

**COMPARISON OF FRICTIONAL RESISTANCE TO SLIDING ON
PRE-ADJUSTED EDGEWISE BRACKETS USING THREE
DIFFERENT METHODS OF LIGATION AND THE EFFECT OF
FLUORIDE MOUTH RINSE ON FRICTION- AN INVITRO STUDY**

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**BRANCH - V
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*I seek the blessings of the **Almighty God** without whose benevolence; the study would not have been possible.*

CERTIFICATE

*This is to certify that the dissertation entitled “**Comparison of frictional resistance to sliding on pre-adjusted edgewise brackets using three different methods of ligation and the effect of fluoride mouth rinse on friction-an invitro study**” done by **Dr. V.R ARUN.,** Post graduate student (M.D.S), Orthodontics (branch V), Tamil Nadu Govt. Dental College and Hospital, Chennai, submitted to the Tamil Nadu Dr. M.G.R. Medical University in partial fulfilment for the M.D.S. degree examination (April 2013) is a bonafide research work carried out by him under my supervision and guidance.*

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DECLARATION

I, **Dr. V.R ARUN**, do hereby declare that the dissertation titled “**Comparison of frictional resistance to sliding on pre-adjusted edgewise brackets using three different methods of ligation and the effect of fluoride mouth rinse on friction-an invitro study**” was done in the Department of Orthodontics, Tamil Nadu Government Dental College & Hospital, Chennai 600 003. I have utilized the facilities provided in the Government Dental College for the study in partial fulfillment of the requirements for the degree of Master of Dental Surgery in the specialty of Orthodontics and Dentofacial Orthopaedics (Branch V) during the course period 2010-2013 under the conceptualization and guidance of my dissertation guide, Professor **Dr.SRIDHAR PREMKUMAR, MDS**.

I declare that no part of the dissertation will be utilized for gaining financial assistance for research or other promotions without obtaining prior permission from the Tamil Nadu Government Dental College & Hospital.

I also declare that no part of this work will be published either in the print or electronic media except with those who have been actively involved in this dissertation work and I firmly affirm that the right to preserve or publish this work rests solely with the prior permission of the Principal, Tamil Nadu Government Dental College & Hospital, Chennai 600 003, but with the vested right that I shall be cited as the author(s).

Signature of the PG student

Signature of the HOD

Signature of the Head of the Institution

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Mr. Dr.Sridhar Premkumar aged 45 years working as **Professor** in Department of Orthodontics and dentofacial orthopedics at the college, having residence address at B-3, Block2, Jains Ashraya Phase III, Arcot road, virugambakkam, chennai-92 (herein after referred to as the 'Principal Investigator')
And

Mr. Dr. V.R Arun aged 29 years currently studying as **Post Graduate student** in Department of Orthodontics and dentofacial orthopedics, Tamilnadu Government Dental College and Hospital, Chennai - 3 (herein after referred to as the 'PG student and co- investigator').

Whereas the PG student as part of his curriculum undertakes to research on *“Comparison of frictional resistance to sliding on pre-adjusted edgewise brackets using three different methods of ligation and the effect of fluoride mouth rinse on friction-an invitro study”* for which purpose the Principal Investigator shall act as principal investigator and the college shall provide the requisite infrastructure based on availability and also provide facility to the PG student as to the extent possible as a Co-investigator.

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College represented by its **Principal**

PG Student

Witnesses

Student Guide

1.

2.

LIST OF ABBREVIATIONS

BI	: Binding.
B-Ti	: Beta titanium.
CEL	: conventional elastomeric ligatures.
Cr	: Chromium
FR	: Frictional resistance.
IN	: Roughness interlocking.
N	: Newton.
NCEL	: Non conventional elastomeric ligatures.
Ni	: Nickel .
NiTi	: Nickel titanium.
NO	: Notching
PH	: Potential of hydrogen.
RS	: Resistance to sliding.
SH	: shearing
SLB	: Self ligating brackets
SS	: Stainless steel .
Ti	: Titanium.
TMA	: Titanium-molybdenum alloy.

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ABSTRACT

Background: Friction has an important role in clinical orthodontics. The friction occurring between archwire and bracket during sliding can considerably reduce the rate of intended tooth movement and produce undesirable movement of the anchor teeth. Two factors determine the amount of friction during sliding mechanics are the coefficient of friction between contacting surfaces and the forces applied between those surfaces. The coefficient of friction is mainly determined by wire roughness, texture, or hardness of the surface which will get altered in complex oral environment. The force applied between bracket and arch wire is determined by the force exerted by the ligation. The present study focused to evaluate the effect of three methods of ligation and to find out the role of fluoride mouth rinse on friction .

Aim: To compare the frictional resistance to sliding on pre adjusted edge wise brackets using three different methods of ligation and the effect of fluoride application on friction.

Methods: 90 custom made bracket mounting templates were divided into three ligation groups - elastomeric modules, stainless steel ligatures and super slick. Each group consisted of 30 samples. Tests were conducted in three environmental conditions namely dry, wet by immersed in artificial saliva and after fluoride mouth rinse application. Testings were conducted on Precision Universal Tester using 5N of tensile force to pull the archwire through the bracket slot at a crosshead speed of 20 mm/min through a distance of 5 mm. The force required to initiate the sliding (static friction), which is represented by a peak in the beginning of digital readout was recorded.

Results: Super slick ligation demonstrated significantly lower friction than other two groups ($p < 0.05$) in all the three environmental conditions. When each ligation was tested under three conditions, friction significantly increased after fluoride application ($p < 0.05$).

Conclusion: Low friction ligatures like super slick can be used as an effective means to reduce friction. Prophylactic agents containing fluoride can have a deleterious effect on sliding as it is increasing the friction due to its ability to change the surface morphology at the sliding interface.

Key words:- Friction, Superslick, Fluoride mouth rinse.

INTRODUCTION

INTRODUCTION

Friction can be defined as a force that opposes or delays the movement of two bodies in contact². Sliding is responsible for a considerable amount of friction in the interface bracket/orthodontic wire^{111,10}. In orthodontics, friction has been implicated in reducing the rate and efficiency of sliding mechanics¹⁴. It has been shown that between 12% and 60% of applied force in fixed appliances is lost to friction⁵⁴. There are two types of friction: static and kinetic. Static friction occurs until the force is great enough to overcome the initial resistance to movement of the object; kinetic friction then opposes the continuation of the movement⁹. The kinetic friction is irrelevant in orthodontic tooth movement because continuous motion along an archwire rarely, if ever, occurs⁹. Inherent local factors concerning the appliances used in orthodontic treatment, such as the brackets, the archwires, the type of alloy and ligature, the intensity of the orthodontic force, and the bracket/wire corrosion influence the friction force produced during tooth movement^{3,104,123,88,25,45}. In addition, the conditions inherent in the buccal environment such as temperature variation, pH variation, humidity, presence of dental biofilm in association with the aforementioned local factors, can alter the forces involved^{85,94,97}.

Two factors determine the amount of friction during sliding mechanics: the coefficient of friction between contacting surfaces and the forces applied between those surfaces. The method of ligation determines how tightly the wire is engaged within the bracket slot and is therefore directly related to frictional resistance to sliding^{6,58,109,112,38,42,63}. Conventional brackets are traditionally

ligated with elastic ligatures or stainless steel ties. Loosely tied stainless steel ligatures are generally thought to generate less friction than standard elastomeric ligatures, although the increase in chairside time required to manipulate stainless steel ligatures has meant that they are still less popular in the clinical situation than elastomers⁶. Consistent ligation forces are difficult to attain with SS ligatures even for a trained operator⁴⁹. The larger the ligating or applied force exerted on the wire-bracket apparatus, the greater the frictional force^{93,28,114}. The advantages of using elastomeric ligatures are that they can be applied quickly, are comfortable to the patient, and are relatively hygienic and inexpensive¹¹⁶. It also has a variety of color options available and are popular among younger patients. The majority of the studies agrees that loosely tied SS ligatures produce less friction than the standard elastomeric ligatures^{84,33,6}. But a few studies have shown that frictional forces produced by elastomeric ligatures and stainless steel ligatures are quite similar^{28,24}, whereas some others claimed that friction produced by elastomeric ligature are less than that caused by stainless steel ligatures^{106,98}. In recent years various modified elastomeric ligatures are introduced in an attempt to reduce friction. These include modules coated with hydrophobic coating using Metafasix technology (Super SlickTM). This coating changes the elastomeric surface characteristics, rendering it slippery on contact with water or saliva.

Fixed appliances in orthodontics involve brackets and archwires that are metallic. With current orthodontic treatment, superelastic nickel-titanium wire is often used for alignment phase, with beta titanium and stainless steel (SS)

wires most frequently used for space closure and finishing phase^{60,86}. As a result, beta titanium and SS wires tend to be used more often, leaving them exposed to the aqueous oral environment for a longer period of time. It is not uncommon during finishing to have the same wire in the mouth for up to 12 months⁸⁰. During orthodontic treatment, practitioners recommend that their patients use mouthwashes, especially since most are adolescents who do not always follow a satisfactory oral-hygiene regimen and have a high risk of dental caries¹⁰⁵. Fluoride-containing products such as toothpastes and mouthwashes are recommended during orthodontic treatment to reduce the risk of the development of white spots around orthodontic brackets¹⁰⁸. Although both beta titanium and SS alloys form corrosion-resistant passivation layers^{25,44,127}, these protective oxide layers can be chemically disrupted, leading to corrosion susceptibility^{64,125}. In addition to corrosive surface changes, it has also been reported that experimental fluoride solutions degrade the tensile strength and microhardness of beta titanium and SS archwires^{73,56,55}.

Most of the studies carried out in the past focused to evaluate the material properties and surface characteristics of brackets and arch wires involved in friction. And most of them are carried out only in dry and wet condition. Little is known about the effect of fluoride on friction when different ligation methods are used. The purpose of this study is to investigate the effect of three different ligation method on friction and to evaluate the effect of fluoride mouth rinse on friction.

AIM AND OBJECTIVES

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AIM

To compare the frictional resistance to sliding on pre adjusted edge wise brackets using three different methods of ligation and the effect of fluoride application on friction.

OBJECTIVES

1. To evaluate frictional resistance to sliding on pre adjusted edgewise bracket using three different methods of ligation namely elastomeric modules, stainless steel and super slick.
2. To evaluate frictional resistance to sliding under three different environmental conditions namely dry, wet by immersed in artificial saliva and soaked in fluoride mouth rinse.
3. Comparison of frictional resistance to sliding using three different methods of ligation under three environmental conditions.
4. To evaluate the role of fluoride application on frictional resistance.

REVIEW OF LITERATURE

Review of literature

Mechanical factors influencing friction

Andreasen and Quevedo³⁰ (1970) pointed out that increased tipping of a tooth relative to its adjacent teeth increases the force necessary to overcome friction; that is, the larger the angle of wire deflection into the bracket slot, the larger the horizontal force required for sliding the bracket over the arch wire. They also stated that increased wire sizes increase the force necessary to overcome friction for a bracket sliding over an arch wire.

Hixon et al⁴³ (1970) observed that vibrating the teeth decreased resistance to sliding. They support the laboratory findings that (1) resistance to sliding is largely due to binding and notching that is temporarily released by oral function, and (2) provide no evidence to support the claim of reduced treatment time with self-ligating brackets.

Riley J.L. et al⁹⁸ (1979) compared frictional resistances of round and rectangular wire in plastic and metal brackets. They found more resistance with plastic than with metal brackets and friction increased with wire size and with time in a simulated oral environment.

Frank and Nikolai²⁸ (1980) noted that theoretically at a given bracket slot angulation relative to the archwire, the friction force will increase with increasing wire stiffness. In contrast, their results showed increased friction levels for 0.020- inch round wire compared to the stiffer 0.017- x 0.025- and 0.019 x 0.025 inch rectangular wires. This finding indicated the potential influence that a wire's cross sectional shape can have on frictional resistance.

They speculated that because the round wire, at higher angulations, makes only a point contact with the edge of the bracket-slot while the rectangular wires at the same angulations make broader line contacts, then the round wire experiences higher pressures per unit contact area and indentation (or notching) of the wire occurs. If correct, deformation of the wire would lead to increased friction.

Garner and associates²⁹ (1986) observed scanning electron micrographs of various wire surfaces in an attempt to explain why certain alloys showed larger frictional resistances than others. Their findings suggested that the roughness of the wire surface may account for the variance in frictional magnitudes seen with different wires.

Kelvin L.Baker et al⁶¹ (1987) determined the magnitude of frictional force changes between several sizes of stainless steel orthodontic wires and an edgewise bracket. They concluded that the 0.020 inch wire placed within the 0.022 inch slot of the bracket “filled” the bracket slot to a greater degree than did an 0.018 inch or 0.018 X 0.025 inch wire in the occluso gingival dimension. Arch wire dimensions more closely approximating that of the bracket slot decreased the potential for binding forms of friction caused by wire distortion. As a contributing factor, the 0.020 inch wire had a greater stiffness. This will decrease the likelihood of wire distortion under load.

Kusy and colleagues⁶⁶ (1988) using laser spectroscopy quantitatively assessed the surface roughnesses of four orthodontic archwires composed of different alloys. Their results showed that nickel-titanium wires have roughest surface

followed by beta titanium and cobalt-chromium. The “least rough” wire was stainless steel.

Garner, Allai, and Moore²⁹ (1986); Drescher, Bourauel, and Schumacher²¹ (1989); Tidy¹²¹ (1989); Kapila et al⁵⁸ (1990); Kusy and Whitley⁶⁸ (1990); Kusy and Whitley (2000)⁷² determined that the wire material was an important factor in determining resistance to sliding. Their results showed TMA, beta-titanium wires to be associated with the highest friction levels followed by Nitinol, cobalt-chromium, and stainless steel.

Drescher and associates²¹ (1989) found that an increased bracket width resulted in decreased friction. Their protocol permitted the bracket to tip under a given retarding force; this design intended to simulate the effect of intrinsic biologic factors such as bone density, root configuration, and occlusion. They found that when teeth and bracket slots are initially misaligned, greater relative friction and archwire binding would exist with wide brackets compared to narrow ones. On the other hand, after the teeth and the bracket slots are aligned and parallel, wide brackets would show less tipping during space closure than narrow brackets and, therefore, less binding of the archwire and lower friction.

Tidy¹²¹ (1989) tested brackets in the laboratory conditions and showed that, slot size did not play a significant role in determining the frictional resistance of a given bracket.

Kusy and Whitley⁶⁸ (1990) in their study found out that greater the titanium content of the wire alloy, the larger the wire’s reactivity or ability to form

metal-metal bonds. They also noted that a clear relationship does not always exist between surface roughness and the coefficients of friction.

Angolkar et al³ (1990); Downing, McCabe, and Gordon²⁰ (1994) have proven that a precise amount of frictional resistances may never exist among different wire alloys. They observed that titanium alloy archwires often producing increased frictional levels in laboratory studies.

Sunil Kapila et al⁵⁸ (1990) in their study evaluated friction between edgewise stainless brackets and orthodontic wires of four alloys. Stainless steel (SS), cobalt-chromium (Co-Cr), nickel-titanium (NiTi), and titanium (β -Ti) wires of several sizes were tested in narrow single (0.050-inch), medium twin (0.130-inch) and wide twin (0.180-inch) stainless steel brackets in both 0.018- and 0.022-inch slots. The wires were ligated into the brackets with elastomeric ligatures. β -Ti and NiTi wires generated greater amounts of frictional forces than SS or Co-Cr wires for most wire sizes. Increase in wire size generally resulted in increased bracket-wire friction.

Kusy and Whitley⁶⁸ (1990); Ireland et al⁴⁷ (1991); Omana, Moore, and Bagby⁹⁰ (1992) shown that ceramic brackets may show similar or even smaller friction magnitudes than stainless steel brackets.

Bednar's group⁶ (1991) determined that the selfligating SPEED bracket did not always produce the smallest frictional resistance. They noted much larger resistance with the SPEED bracket when a 0.016- x 0.022-inch stainless steel wire was used. They reasoned that the bracket's spring clip pressed the larger archwire against the base of the bracket-slot, increasing resistance.

But **Shivapuja and Berger**¹⁰⁹ (1994); **Taylor and Ison**¹¹⁷ (1996) found that three types of self-ligating brackets all showed significantly less frictional resistance than conventional brackets tied with steel or elastomeric ligatures. This may be explained, in part, on the basis of the great variety of brackets in combination with the great variety of ligatures and their various forms of application. **Kapur, Sinha, and Nanda**⁵⁹ (1998); **Pizzoni, Ravnholt, and Melsen**⁹⁴ (1998); **Mendes and Rossouw**⁸¹ (2003) validated these findings.

Kusy et al⁶⁷ (1991) found that stainless steel brackets tend to generate less frictional resistance than ceramic brackets.

Proski et al⁹⁶ (1991) used a surface profilometer to measure surface roughness of twelve different wires, nine of which were composed of nickel-titanium alloys. No correlation could be found between surface roughness and frictional resistance between the different wire alloys.

Ireland A.J. et al⁴⁷ (1991) investigated the friction in buccal segment attachments using a buccal segment model in steel and ceramic brackets. The results indicated that friction during overjet reduction is minimized by using larger dimension rectangular wires and by using steel rather than nickel titanium. Stainless steel brackets showed greater frictional resistance than ceramic brackets, but only when used with the smaller rectangular wires.

Omana et al⁹⁰ (1992) additionally discovered a tremendous variation in the friction levels produced by different types of ceramic brackets. Some of them showed much larger friction value than the stainless steel bracket, while others showed comparable values. They attributed the reduced, ‘stainless steel like’

frictional values of certain ceramic brackets to the ability of an injection-molding manufacturing process to produce very smooth ceramic surfaces.

A Downing et al²⁰ (1994) found that increasing the archwire diameter increased the frictional force.

Janet L Vaughan et al⁵⁰ (1995) in their study concluded that the increased wire size lead to greater frictional force. The frictional forces were generally greater with a rectangular wire than with round wire. They ranked wire alloys in order from lowest to highest friction as stainless steel, cobalt-chromium, nickel titanium, and beta-titanium.

Edwards GD, Davies EH, Jones SP²⁴ (1995) in their investigation compared the effect of various orthodontic ligation techniques on the static frictional resistance of stainless steel brackets and archwires under both dry and wet conditions. The techniques studied were elastomeric modules tied conventionally and in a 'figure of 8' pattern, stainless steel ligatures, and Teflon-coated ligatures. A pair of ligature locking pliers was modified so that ligatures could be placed with a standardized force. Finally, the four methods of ligation were directly compared on a specially constructed testing apparatus. Results revealed that elastomeric modules tied in a 'figure of 8' pattern produced significantly more friction than any other method tested, under both dry and wet conditions. No significant differences in frictional resistance were found between conventionally tied elastomeric modules and stainless steel ligatures. Teflon-coated ligatures, however, were associated with the lowest friction forces.

Kusy RP, Whitley JQ⁷⁰ (1997) discussed the classical laws of friction in relation to orthodontic mechanics. They pointed out that certain principles remain true under the parameters imposed by orthodontics while others do not. The first law, states that friction is proportional to the normal force, the constant being the coefficient of friction. This law is followed without exception in orthodontic movement. The second law that notes the independence of friction from the apparent contact area is usually obeyed in orthodontics. But the third law, “Coulomb’s Law” regarding the independence of friction magnitude from sliding velocity, most often never holds true when it comes to moving teeth with brackets and archwires. This departure from classical friction is in part due to the extremely slow velocity of orthodontic tooth movement as well as the fact that the velocity is ever changing.

Nanda and Ghosh⁸² (1997); Rossouw et al¹⁰¹ (2003) stated that for each pair of the contacting surfaces, there are two coefficients of friction. The first is the static coefficient of friction associated with the resistance to be overcome to initiate movement. The second is the kinetic coefficient of friction associated with the resistance continually overcome to keep a moving body moving at a constant speed. Based upon the classic laws of friction, the static coefficient of friction will be larger than the corresponding kinetic coefficient of friction.

Luca Pizzoni et al⁹⁴ (1998) concluded that the selection of bracket design, wire material and wire cross section significantly influences the forces acting in a continuous arch system. They also showed that round wires had a lower friction than rectangular wires.

Braun et al⁸ (1999) studied resistance to sliding using different wire sizes, different ligation methods, and different angles (binding). They concluded that “frictional resistance was effectively reduced to zero each time minute relative movements occurred at the bracket/ wire interfaces. Factors such as the degree of dental tipping, relative archwire/slot clearances, and method of tying did not have a measurable effect on frictional resistance in the simulated dynamic of the oral environment”.

O'Reilly et al⁸⁷ (1999) oscillated the bracket while measuring the resistance to sliding, producing the same temporary release of binding. They concluded that “If one considers the clinical situation, where there is intermittent movement between the bracket and archwire, then clinically we may not be looking at true friction, but rather a binding and releasing phenomenon.

Articolo and Kusy⁷⁴ (1999) studied resistance to sliding as a function of angulations of the arch wire to conventionally ligated edgewise brackets using various combinations of archwires and brackets. They noted that the binding influence on friction became greater as the wire-bracket angulation increased.

Brian P. Loftus et al⁷⁶ (1999) evaluated friction during sliding tooth movement in various bracket–arch wire combinations. They found that the conventional ceramic brackets generated significantly higher friction than the other brackets tested. Beta titanium arch wires produced higher frictional forces than nickel titanium arch wires, but no significant differences were found between each of the two and stainless steel arch wires.

Kusy and Whitley⁷¹ (1999) in a study on the influence of arch wire and bracket dimension on sliding mechanics further subdivided the resistance to sliding (RS) was in to Ploughing (PL),

Roughness interlocking (IN) and

Shearing (SH) components

So resistance to sliding $RS=PL+IN +SH$.

When these concepts are combined, equations for general expression of resistance to sliding can be given as $RS=PL+IN+SH+BI+NO$. They also pointed out that, when this critical contact angle is reached and surpassed, binding of the archwire and later notching of the wire begin to overwhelm classic friction.

Proffit⁹⁵ (2000) stated that as the teeth begin to move under the force of the elastically deformed wire, they begin to align themselves. Alignment of the teeth often results in a decrease in the total distance between brackets in the arch. This decrease is best visualized by the resulting excess archwire seen beyond the distal ends of the most distal brackets following alignment. While the teeth are moving toward their ideal positions as the appliance is deactivating, the excess archwire usually slides past the surfaces of the adjacent brackets. In this way, the leveling and aligning phase at the beginning of orthodontic treatment employs sliding mechanics and, therefore, is also subject to the influence of friction. The stiffness of an archwire is not only related to the dimensions of the wire, but also to its cross-sectional shape, and its material composition. It is also influenced by the length of wire between brackets as

determined by interbracket distance and any addition of loops, bends, or helices to the length of wire.

Kusy and Whitley⁷² (2000) verified the theory put forth by **Frank and Nikolai²⁸ (1980)** that frictional force increases with increasing wire stiffness. They found that, as bracket slot angulation was increased relative to a straight length of archwire, wire alloys having greater material stiffness such as cobalt-chromium or stainless steel wires produced greater binding and greater resistance to sliding. They also noted that interbracket distance significantly affected frictional resistance. Under their testing conditions, as interbracket distance was reduced from 18 mm to 8 mm, binding of the wire in the bracket increased about two-and-a-half times.

Thorstenson and Kusy³⁵ (2002) compared a series of self ligating brackets with conventionally ligated brackets in a similar but more extensive way, studying the effect of friction to binding on resistance to sliding in a steady state laboratory model under both dry and wet (saliva) conditions. They reported that, with both conventional and self-ligating brackets, binding also increased as the wire-bracket angulation increased.

Rossouw's et al¹⁰¹ (2003) noted that at extremely low velocity it is impossible to distinguish static and kinetic frictional resistance into distinct phases and that the resultant instability in sliding motion may lead to cycles characterized by “sticking and slipping” variably involving a bracket (or tube) and wire.

Thorstenson and Robert P. Kusy³⁴ (2003) compared the RS values of two SS bracket designs with bosses that prevent contact between the ligation and the

archwire were with those of two SS bracket designs without these bosses. When clearance existed for the SS archwire-bracket couples, the coefficients of friction of all brackets ranged from 0.13 to 0.21 in the dry state and from 0.16 to 0.22 in the wet state, confirming that the bumps in the slot do not reduce friction.

Kevin Mendes⁸¹ et al (2003) concluded that ion implantation of nickel-titanium and beta-titanium wires, as well as the bracket surfaces are effective means to reduce friction. An even greater reduction in friction can be obtained by using self-ligating brackets and the ion implanted wires.

Edward Mah²³ (2003) evaluated the influence of a variable moment, simulating mastication, placed at the bracket-archwire interface to determine its effects on friction. These results suggest that self-ligating brackets produce less dynamic friction than conventional brackets, and larger-diameter archwires produce greater amounts of dynamic friction.

Cacciafesta V et al¹⁰ (2003) showed that stainless steel brackets generated significantly lower static and kinetic frictional forces than both conventional stainless steel and polycarbonate self-ligating brackets, which showed no significant differences between them. All brackets showed higher static and kinetic frictional forces as the wire size increased.

Henao SP and Kusy⁴¹ (2004) stated that when clearance was substantial, the self-ligating brackets with slides performed better than those with clips. Indeed, these self-ligating brackets maintained low frictional values for wires up to 0.020X 0.020-inch. However, as malocclusion became more prevalent and

archwire size reduced overall clearance, the two self-ligating designs of slides and clips lost distinction.

Clarice Nishio⁸⁵ (2004) showed that brackets had frictional force values that were statistically significant in progressive order of: stainless steel bracket, ceramic bracket with a metal reinforced slot, and traditional ceramic bracket with a ceramic slot. The frictional force values were directly proportional to the angulation increase between the bracket and the wire.

Franchi et al⁷⁷ (2008) compared the frictional forces generated by active and passive self-ligating brackets, conventional elastomeric ligatures, and nonconventional elastic ligatures (Leone) were used with 2 rectangular SS wires . They concluded that an increase in wire size led to an increase in friction in all bracket-archwire combinations.

Giovanni Matarese et al³² (2008) found that the frictional forces can be reduced during alignment by using small dimensions, and less stiff wires, thereby inducing the wire to slide in the slots. Under such conditions, the force required by the orthodontic wire to overcome resistance to sliding is reduced. They also found that no significant differences were found between Elastomeric (EM) and SS ligatures. However, the greater standard deviation of SS ligatures compared with EM is worth noting. This demonstrates how difficult it is to standardize the magnitude of ligation force generated by SS ligatures with methods that can be used in-vivo.

S. Jack Burrow⁹ (2009) in a critical review about friction and resistance to sliding in orthodontics stated that for all practical purposes, kinetic friction is

irrelevant in orthodontic tooth movement because continuous motion along an archwire rarely if ever occurs. In sliding mechanics, we are dealing with a quasi-static thermodynamic process, which means that the process happens slowly and goes through a sequence of states that are close to equilibrium. He also stated that the contributions of friction, binding, and notching to resistance to sliding can be understood best by considering the 3 stages in the active phase of moving teeth.

1. The first is the early stage of sliding as the tooth tips and contact of the wire with the corner of the bracket begins to occur; both friction and binding contribute to resistance to sliding: Resistance to sliding, $RS = \text{Classical friction, } FR + \text{Binding, } BI$.

2. In stage 2, the contact angle increases between the bracket and the wire, when binding is the major source of resistance and friction becomes inconsequential: $RS = BI$.

3. In stage 3, if the contact angle becomes steep enough, notching of the wire occurs, and both friction and binding become negligible: $RS = NO$.

Ariana Pulido Guerrero et al⁴ (2010) evaluated frictional forces between ceramic brackets and archwires of different alloys compared with metal brackets. Tests were performed on three ceramic brackets and one stainless steel bracket in artificial saliva. Arch wires were pulled through the slots at a crosshead speed of 10 mm/min. They concluded that metal brackets produced the lowest frictional forces. Resistance to sliding was proportional to the angle created between the bracket and the wire. Ni-Ti wires had the lowest mean

frictional force values. The addition of metal slots in the polycrystalline brackets did not significantly decrease frictional values.

Sennay Stefanos et al¹⁰⁷ (2010) compared friction between various self-ligating brackets and archwire couples during sliding mechanics. They concluded that passive self-ligating brackets have lower static and kinetic frictional forces compared with active self-ligating brackets when coupled with 0.019 x 0.025-in stainless steel wire.

Wook Heo, Seung-Hak Baek¹²⁸ (2011) compared frictional properties according to the amounts of vertical displacement (VD) and horizontal displacement (HD) of teeth and bracket types during the initial leveling/alignment stage. Combinations of self-ligating brackets and 0.014 inch NiTi archwires were tested for static and kinetic frictional forces. They concluded that the frictional properties of SLBs would be different between VD and HD of teeth. So it is necessary to develop SLBs with low friction in both VD and HD of teeth.

Takeshi Muguruma et al¹¹⁵ (2011) evaluated the effects of a diamond-like carbon coating (DLC) on the frictional properties of orthodontic wires. Although the stainless steel wire showed smoother and harder surface characteristics than the nickel-titanium wire, the stainless steel wires had greater frictional forces than the nickel-titanium wires. The stainless steel wires had wider cross-section dimensions and a higher value of the elastic modulus than the nickel-titanium wires, and this should have affected binding and notching. The harder surface of the DLC-coated wires not only reduces

friction, but also reduces the effects of binding and notching. In addition, the DLC layer on the stainless steel and nickel-titanium wires showed a lower elastic modulus than the surface layer on the as-received wires.

Giancarlo Cordasco et al³¹ (2012) found that the resistance to sliding (RS) increased significantly as the bracket angulations increased in both the self-ligating and conventional ligation bracket systems. The RS values recorded in the conventional ligation system were significantly higher than those in the self-ligating system at every tested angulation.

Environmental Factors influencing Friction

Andreasen and Quevedo³⁰ (1970) evaluated friction forces in the 0.022 X 0.028 edgewise bracket in vitro. Seventy-two possible combinations of archwire and brackets were measured under both dry and with saliva acting as a lubricant, to determine (1) the force necessary to overcome friction between bracket and arch wire and (2) the coefficient of friction. The differences between force measurements made with saliva as a lubricant and those made with a dry wire were insignificant.

Hixon et al⁴³ (1970); Thurow¹²⁰ (1975) proposed that oral forces and the resultant movement or “jiggling” of the teeth within the parameters of periodontal ligament tension and compression significantly reduces the friction levels that might exist within an orthodontic appliance during tooth movement.

Thurow¹²⁰ (1975) indicated that saliva serves as an excellent lubricant and that the teeth in function provide a “walking effect” of the bracket along the arch wire.

Frank and Nikolai²⁸ (1980) explained that occlusion and masticatory action alter the force levels between the bracket and wire so that any “friction locks” are broken and then reset over and over again.

Park HY, Shearer TR⁹² (1983) stated that in an oral environment, orthodontic brackets are exposed to potentially damaging physical and chemical agents. These conditions may affect the amount of metal corrosion.

Jan G. Stannard, Jeanne M. Gau and Milford A. Hanna¹¹⁴ (1986) evaluated kinetic coefficients of friction for stainless steel, beta-titanium, nickel-titanium, and cobalt-chromium arch wires measured on a smooth stainless steel or Teflon surface. Coefficients of friction were determined under dry and wet (artificial saliva) conditions. Artificial saliva increased friction for beta titanium, and nickel-titanium wires sliding against the stainless steel surface. Artificial saliva did not increase friction for cobalt chromium, stainless steel sliding against stainless steel, or stainless steel wire on Teflon compared to the dry condition. Stainless steel and beta-titanium wires sliding against stainless steel and stainless steel wire on Teflon showed the lowest friction values for the wet condition. Lubrication generally will reduce friction values for rough materials.

Kelvin L.Baker et al⁶¹ (1987) determined the magnitude of frictional force changes between several sizes of stainless steel orthodontic wires and an edgewise bracket (0.022 x 0.028 inch slot) The force values in the saliva substitute medium were compared with those produced in a dry control and

glycerin. They validated the role of saliva as a lubricating medium to reduce the friction.

Kusy, Whitley, and Prewitt⁶⁷ (1991) evaluated coefficient of friction in dry and wet (saliva) states for stainless steel , cobalt-chromium , nickel titanium and beta titanium wires against stainless steel or polycrystalline alumina brackets . Eight arch wire- bracket combinations were tested in the dry state at 34⁰ c and in the wet state with human saliva at 34⁰ c. They found out that that in the wet state, the kinetic coefficient of all- stainless steel combinations significantly increased over the dry state .This reduced friction under dry condition was due to the chemically passive chromium oxide surface layer . In contrast, all beta titanium wire combinations in the wet state decreased to 50% of the values in the dry state . They concluded that saliva promotes both lubricious and adhesive behavior, may lubricate certain wire/bracket alloy couples while acting as an adhesive for couples of other alloys. In stainless steel combinations, saliva has more an adhesive behavior than a lubricating one.

Jost-Brinkman and Miethke⁵³ (1991) reported that “additional tooth movement by occlusal load resulted in significant reduction of friction magnitude.”This effect can be attributed to the same temporary release of binding or notching observed in laboratory studies.

Ireland, Sherriff, and McDonald⁴⁷ (1991); Edwards, Davies, and Jones²⁴ (1995); Kusy and Whitley⁷² (2000); Thorstenson and Kusy, (2002)³⁵;

Henao and Kusy⁴¹ (2004) had shown that saliva has no significant or consistent advantage in reducing friction.

Downing A, McCabe JF, Gordon PH²⁰ (1995) evaluated the effect of artificial saliva on the static and kinetic frictional forces of stainless steel and polycrystalline ceramic brackets in combination with 0.018-inch round and 0.019 x 0.025-inch edgewise archwire sizes made of stainless steel, nickel-titanium and beta-titanium archwire materials, under a constant ligature force. In all cases, artificial saliva had the effect of increasing the frictional force when compared to the dry state.

Toumelin-Chemla F, Rouelle F, Burdairon G¹²² (1996) evaluated corrosive properties of fluoride-containing odontologic gels against titanium. These substances have a pH range of about 3.5 to 7.0. In an acidic medium, a small amount of fluoride induces the formation of hydrofluoric (HF) acid according to the following reaction: $\text{NaF} + \text{H}^+ = \text{HF} + \text{Na}^+$. HF acid is known to dissolve the surface oxide layer by the following reactions: $\text{Ti}_2\text{O}_3 + 6\text{HF} = 2\text{TiF}_3 + 3\text{H}_2\text{O}$, $\text{TiO}_2 + 4\text{HF} = \text{TiF}_4 + 2\text{H}_2\text{O}$, and $\text{TiO}_2 + 2\text{HF} = \text{TiOF}_2 + \text{H}_2\text{O}$.

Nanda and Ghosh⁸² (1997) stated that the biological factors that affect bracket-wire friction includes saliva, plaque, acquired pellicle, and corrosion.

Kusy and Whitley⁷⁰ (1997) evaluated frictional forces in dry and wet conditions and suggested that the stainless steel archwire showed the lowest frictional forces and beta titanium archwire showed the highest values in dry conditions. It was also reported that, in artificial saliva condition, the frictional

force of stainless steel archwire increased significantly and that of beta titanium archwire decreased.

Braun and colleagues⁸ (1999) Using an orthodontic model, applied random perturbations to a test wire or bracket. Each perturbation produced a corresponding decline in frictional resistance with the resistance levels of more than 95% of the tests dropping completely to zero.

Eliades T, Eliades G, Athanasiou AE, Bradley TG²⁶ (2000) **Eliades T, Zinelis S, Eliades G, Athanasiou AE²² (2002)** evaluated in-vivo aging of orthodontic components which show signs of degradation such as morphological changes and surface alterations from corrosion, wear, and formation of integuments.

Kusy RP, Whitley JQ⁷² (2000) evaluated resistance to sliding of orthodontic appliances in the dry and wet states using stainless steel ligatures. Using miniature bearings to simulate contiguous teeth, five experiments each were run in the dry or wet states with human saliva at 34⁰ C as a function of four archwire alloys, five interbracket distances, and two bracket engagements. Outcomes were objectively analyzed. They found out that unlike earlier results in the passive configuration, in the active configuration couples comprised of titanium alloys (NiTi and (beta-Ti) had higher resistance to sliding in the wet versus the dry state.

Proffit⁹⁵ (2000) stated that the oral cavity is a changing environment. Whether influenced by the tongue, the jaw, or the peri-oral muscles, the mouth and its

structures are subject to the effects of a variety of forces. These forces could impact the position of the teeth in their respective arches.

Thorstenson GA, Kusy RP³⁵ (2002) compared resistance to sliding between different self-ligating brackets with second order angulation in dry and saliva states. In all cases, an 0.018 * 0.025-in stainless steel archwire was drawn through each bracket at a rate of 10 mm/min over a distance of 2.5 mm. Both the dry and the wet (human saliva) states were evaluated at 34°C. The RS of brackets with active clips ranges from average values of 12 to 47 cN in the dry state and from 22 to 54 cN in the wet (saliva) state. Based on their intercepts, the brackets with active clips exhibit greater RS values than those with passive slides in either the dry or the wet states.

Iwasaki et al⁴⁹ (2003) found that the vibrations introduced when the patient chewed gum did reduce static friction, but did not eliminate friction altogether. They concluded that masticatory forces do not consistently and predictably decrease friction. It is clear that teeth are subject to a wide array of light and heavy forces on a daily basis, but the effect of these forces upon orthodontic mechanics and tooth movement has yet to be clarified.

Watanabe I, Watanabe E (2003)¹²⁷ studied the influence of fluoride concentration on the corrosion of titanium and titanium alloys. They reported that the fluoride ions in the prophylactic agents cause corrosion and discoloration of titanium and its alloys.

Smith DV, Rossouw PE, Watson P¹¹³ (2003) & Mendes K, Rossouw PE⁸¹ (2003) showed that when SS wires are used, saliva may not act as a lubricant.

Instead, saliva may increase the friction and present an adhesive interference, caused by increased surface tension in the archwire.

Thorstenson and Robert P. Kusy³³ (2003) compared the effects of ligation type and method on the resistance to sliding of orthodontic brackets with second-order angulation in the dry and wet state. They concluded that for SS couples, the kinetic coefficient of friction values in the dry state was generally lower than those in the wet state.

A-Mayouf AM, Al-Swayih AA, Al-Mobarak NA¹ (2004) studied the effect of fluoride on the electrochemical behavior of Ti and some of its alloys for dental applications. Corrosion of titanium and its alloys are enhanced in an acidic environment. The F-ions in the solution combine with H⁺ ions to form HF, even at low fluoride concentrations. So dental hygiene products containing fluoride ions can attack the oxide film formed on titanium surfaces, and this suggests problems regarding the dental use of titanium.

Ji-Hoon Park⁵² (2004) measured frictional forces between lingual brackets and archwires in dry and with artificial saliva. A significant difference was observed between the dry and the artificial saliva conditions. Beta titanium archwire showed higher frictional force in the dry condition than in the artificial saliva condition as Kusy stated, but the effects of artificial saliva were different depending on the bracket-archwire couples.

Kao CT et al¹³ (2006) compared frictional resistance after immersion of metal brackets and orthodontic wires in a fluoride-containing prophylactic agent. Each test condition contained 10 brackets-wire samples. Three types of

mandibular incisor stainless-steel metal brackets were used. Two stainless steel wires were used: 0.018 in (0.46 mm) and 0.019 * 0.025. Two titanium-based orthodontic wires were used: 0.019 * 0.025-in heat-activated nickel-titanium and 0.017 * 0.025-in beta-titanium alloy wire. 0.2% APF (0.2 mass % NaF 0.17 mass % H₃PO₄, pH 3.5) solution and pH 6.75 adjusted artificial saliva solution was used. The ligation between the bracket and wire was a clear Elastik module. The brackets and archwires were cleaned with alcohol wipes before the modules were tied with mosquito forceps, 25 mm from the lower end of the archwire, to form a test unit. All units in the experimental groups were soaked in 0.2% APF for 24 hours before testing. The control groups were immersed in pH 6.75 artificial saliva solution for 24 hours before testing. Testing was performed on an EZ-test machine (Shimadzu, Tokyo, Japan) with a crosshead speed of 10 mm per minute over a 5-mm stretch of archwire. A plumb line was hung to ensure that the bracket mount was parallel with the vertical line scribed on the steel bar base of the bracket mount assembly. The archwire was drawn through the bracket as the crosshead moved inferiorly at 10 mm per minute. They concluded that the frictional resistance of the wires and brackets increased in the acidic 0.2% APF solution. The results of increased frictional levels might be a longer treatment period and loss of anchorage control.

Max Hain, Ashish Dhopatkar, and Peter Rock³⁸ (2006) examined the stability of the coating and compared the frictional properties of coated modules with those of other common ligation methods. The effect of different

methods of saliva application on the slick coating was assessed. For this test, Super-slick modules were not presoaked in saliva; instead, a drop of saliva was applied to the test unit immediately before each test. Immersion in saliva had no detrimental effect on the coating. Frictional resistance was reduced after soaking uncoated modules in saliva for a week, but they still produced 50% more friction than the slick modules. Differences in the application of saliva to the test apparatus can have a significant effect on the performance of slick modules.

Burrow SJ⁹ (2009) stated that the debris in archwire can potentially increase friction, but it is only one of the factors involved in the resistant force system.

Isabella Silva Vieira Marquesa et al⁴⁸ (2010) showed significant positive correlations between the degree of debris on the archwire surface, surface roughness, and friction. However, the correlation between friction and debris was less significant than the correlation between debris scores and roughness.

Chia-Tze Kao, Jia-Uei Guo, and Tsui-Hsien Huang¹² (2011) compared friction force between corroded and noncorroded titanium nitride plating of metal brackets. The metal brackets selected were 0.022 X 0.028-in slot The 0.019 X0.025-in stainless steel wire was used for the friction test. The ligation between the bracket and the wire was a clear AlastiK module The bracket and archwire were cleaned with alcohol wipes before the test. The testing solutions used in the present study were distilled water, artificial saliva and 1.23% acidified phosphate fluoride (APF) solution. Testing was performed on an EZ-test machine with a crosshead speed of 10 mm per minute over a 5-mm stretch

of archwire .The study showed that corrosion potential was similar between the control and TiN-coated groups in artificial saliva and 1.23% APF solutions . When the brackets were electrochemically corroded in artificial saliva, the control group had a higher corrosion potential than did the TiN-coated group . It was demonstrated that TiN-coated brackets have good anticorrosion properties in chloride-containing artificial saliva. However, the result was controversial for TiN-coated brackets in 1.23% APF solution.

Saulo Regis et al¹⁰³ (2011) stated that clinical use causes surface alterations in metallic orthodontic brackets, with distinct patterns of alterations for different brands. Differences in morphology after use are smaller than those found in the as-received brackets among brands. Distinct frictional behaviors were observed for each bracket brand with clinical use. There were 10% to 20% increase between retrieved and as received brackets, whereas the Mini Standard Edgewise brackets remained unaffected.

Julie E. Olson et al⁸⁹ (2012) evaluated archwire vibration and stick-slip behavior at the bracket archwire interface .They concluded that significant differences in bracket-archwire frictional resistances with variations in amplitude of archwire vibration. Medium and high amplitude vibrations induced cause statistically significant reductions in the time required to overcome friction compared with low-amplitude values.

Effect of ligation on friction

Andreasen and Quevedo³⁰ (1970) stated that the normal force applied by ligature has a significant influence in determining the frictional resistance developed within an orthodontic system.

Paulson, Speidel, and Isaacson⁹³ (1970); Frank and Nikolai²⁸ (1980); Stannard, Gau, and Hanna¹¹⁴ (1986) stated that steel ligatures can be tightly tied or loosely tied, depending upon the reason for their application. The larger the ligating or applied force exerted on the wire-bracket apparatus, the greater the frictional force.

Echols M²² (1975) evaluated the forces necessary for linear displacement of arch wires of various sizes ligated into an 0.022 inch edgewise bracket. They have concluded that heavier the arch wire , greater the force for linear displacement. They recommended force applied to a given tooth or segment be adjusted to compensate for the binding force of the elastic ligature.

Thurrow¹²⁰ (1975) stated that the important point in sliding movements with elastic ligatures is their relatively low maximum force. Binding forces are limited along with all other forces. Wire ligatures have much greater strength, giving them the capacity to apply much higher binding force as teeth slide along the arch. Minor irregularities in the arch can be “locked up” and stop movement much more readily than with elastic ligatures.

Riley JL⁹⁸(1979) showed that steel ligatures generated greater frictional forces than plastic modules and moistening caused an insignificant increase in

friction for steel ligatures and was irrelevant to the plastic modules. But **Frank and Nikolai, 1980²⁸**; **Edwards et al²⁴ (1995)**, **Braun et al⁸ (1999)** showed no difference between the two ligation methods.

Schumacher et al¹⁰⁶ (1990) evaluated the effect of the ligature on the friction between bracket and archwires. The results showed that friction is determined mostly by the sort of ligature and by the way of ligation and not by the dimensions of the different arch wires. Friction caused by Alastics is significantly less than friction caused by steel-ligatures.

Kapilla and colleagues⁵⁷ (1990) proposed that the reason that wide brackets were associated with greater frictional levels was that the wider bracket tended to stretch its elastomeric ligature more, resulting in a larger normal force.

Bednar JR, Gruendeman GW, Sandrik JL⁶(1991) **Kuramae M⁶⁵ (2006)** found that SS ligatures create less friction when compared with elastic ligatures.

Bednar, Gruendeman, and Sandrik⁶ (1991) **Braun et al⁸ (1993)** studied resistance to sliding using different wire sizes, different ligation methods, and different angles (binding). They concluded that factors such as the degree of dental tipping, relative archwire/slot clearances, and method of tying did not have a measurable effect on frictional resistance in the simulated dynamic of the oral environment.

Prasanna Kumar Shivapuja et al¹⁰⁹ (1994) stated that self-ligating bracket systems displayed a significantly lower level of frictional resistance,

dramatically less chair-side time for arch wire removal when compared with polyurethane elastomeric and stainless steel tie -wire ligation for ceramic and metal twin brackets.

Edwards et al²⁵ (1995) concluded that the figure of eight modules appeared to create the highest friction. There was no significant difference in mean frictional force between the conventional module and the SS ligature, but the Teflon-coated ligature had the lowest mean frictional force.

Nigel G Taylor⁸⁴ (1996) stated that ligation with loosely placed ligatures or stretched modules reduced frictional forces in standard straight wire brackets, the reduction being greatest for round archwires. Frictional forces recorded from archwires secured with elastomeric modules showed a steady reduction over a 3-week period, depending on how long the module had been in position on the bracket.

Dwight H Damon¹⁶ (1998) compared the friction produced by three types of conventional twin brackets with three self-ligating twin brackets. When 0.019x0.025 stainless steel wires were drawn through the bracket, a conventional twin ligated with 0-rings produced 388 to 609 times the friction of passive self -ligating brackets. Conventional twins with metal ligatures were found to have friction values, more than 300 times those of passive self-ligating brackets.

Kusy RP, Whitley JQ⁷⁰ (1997); Articolo LC, Kusy RP⁷⁴ (1999);Kusy RP, Whitley JQ(1999)⁷¹ studies have established that, when clearance exists between the archwire and the bracket's slot walls (the passive configuration),

only classical friction (FR) contributes to RS. When clearance no longer exists (the active configuration), elastic binding (BI) additionally contributes to RS.

Edwards GD, Davies EH, Jones SP²⁴ (1995); Voudouris JC¹²⁶ (1997); Dowling PA, Jones WB, Lagerstrom L, Sandham JA¹⁹ (1998) found that the value of FR is equal to the normal force (FN) applied by the ligation multiplied by the kinetic coefficient of friction (mk-FR) of the orthodontic couple. Because FN and mk-FR differ for different ligation types (ie, elastomeric O-rings, SS ligature wires) and methods (ie, figure-O, 'figure-8,' number of twists), previous measurements of FR for similar SS archwire-bracket couples have varied considerably'.

Rock WP, Wilson HJ¹⁰⁰ (1989); Berger JL (1990); Bednar JR; Gruendeman GW, Sandrik JL⁶ (1991); Edwards GD, Davies EH, Jones SP²⁴ (1995); Voudouris JC¹²⁶ (1997) concluded that couples ligated with O-rings had greater FR values than those tied with SS ligature wires. But **Schumacher HA, Bourauel C, Drescher D¹⁰⁴ (1990)** disagreed the above mentioned significance.

Edward Mah²³ (2003) compared friction of self-ligating brackets with stainless steel and ceramic brackets. The results showed that Damon 2 bracket yielded the least friction. These results suggest that self-ligating brackets produce less dynamic friction than conventional brackets, and larger-diameter archwires produce greater amounts of dynamic friction.

Thorstenson and Robert P. Kusy³³ 2003 compared the the RS values of two SS bracket designs with bosses that prevent contact between the ligation and

the archwire were with those of two SS bracket designs without these bosses. They found that when the angulation was just greater than the critical contact angle, the ligation continued to affect the RS. When the angulation greatly exceeded the critical contact angle for binding, the binding component overwhelmed the frictional component, and the effects of ligation type and method were minimal.

Max Hain, Ashish Dhopatkar, and Peter Rock³⁸ (2003) in their in vitro study investigated the effect of ligation method on friction and evaluated the efficacy of the new slick elastomeric modules. Slick modules were compared with regular nonstick modules, stainless steel ligatures, and the SPEED self-ligating bracket system. A custom-made apparatus was constructed to record the resistance to movement of a stainless steel 0.019 * 0.025-in working archwire through test brackets. 21 straight lengths wire each 7 cm long, were used. The overall finding was that slick modules reduced friction by up to 60% compared with their regular counterparts. A figure-8 tie configuration significantly increases frictional resistance. SPEED brackets generated less friction in general than did any other bracket type tested with regular modules in a normal tie configuration. The use of lubricated, slick modules with any of the tested non self-ligating bracket types resulted in a reduction of the friction to below SPEED values. Loosely tied stainless steel ligatures offer the lowest frictional resistance of all the ligation methods tested.

Laura R. Iwasaki, Mark W. Beatty⁴⁹ (2003) examined the effects of bracket ligation forces and mastication on friction when sliding a bracket along an

archwire. The results suggested that vibration introduced by mastication did not eliminate friction when sliding a bracket along an archwire. They found that it is more difficult to standardize the tying strength when using SS ligatures.

Balvinder Khambay et al⁶³ (2004) showed that the Damon II self-ligating bracket and unligated conventional SS bracket produced negligible mean frictional forces with any of the wires. Stainless steel ligatures produced the lowest mean frictional forces. There was no consistent pattern in the mean frictional forces across the various combinations of wire type, size and ligation method. Under the conditions of this experiment, the use of passive self-ligating brackets is the only method of almost eliminating friction.

Henao and Kusy⁴² (2005) confirmed that, while self-ligating brackets produce less friction with smaller wires, there was little difference in resistance between them and the conventional brackets when larger wires were tested. They also stated that lower friction force obtained in the self-ligating groups because of a lower elastic modulus of the nickel titanium alloy (30-60 MPa) and, therefore, a prevailing effect of the wire-securing mechanism on the friction resistance rather than the wire-proper shear force.

Balvinder Khambay, Declan Millett and Siobhan McHugh⁶² (2005) conducted a study to determine the mean tensile force of four different elastomeric modules, the archwire seating force of different ligation methods, and its effect on frictional resistance. Four types of elastomeric module were tested together with a pre-formed 0.09 inch SS ligature. SS ligatures with either wire produced the lowest mean frictional forces, whereas gray modules

produced significantly higher mean frictional forces. The surface characteristics of the modules may have a greater effect on friction than the seating force produced by the ligation method.

Thorstenson GA³⁶ (2005) evaluated friction in self-ligating brackets and conclude that “binding does not appear to be affected by the ligation method” ie, binding is similar with conventional and self-ligating brackets.

Claudio Chimenti et al¹⁵ (2005) did a study to evaluate the in vitro effect of variations in the size of elastomeric ligatures on the static frictional resistance generated by orthodontic sliding mechanics under dry condition. Frictional forces generated by elastomeric ligatures treated with a lubricating material (silicone) were analyzed as well. The static frictional forces of a 0.019 x 0.025-inch stainless steel wire that was ligated to three stainless steel 0.022-inch pre-adjusted brackets with elastomeric ligatures of different dimensions: small, medium, and large. The variation in the dimensions of the elastomeric ligatures can influence significantly the static frictional resistance generated by orthodontic sliding mechanics in the buccal segments. Small and medium elastomeric ligatures produced a significant decrease (13–17%) in the static frictional force when compared with large ligatures.

Max Hain, Ashish Dhoptkar, and Peter Rock³⁸ (2006) compared different ligation methods on friction. In their in-vitro study they examined the stability of the coating and compared the frictional properties of coated modules with those of other common ligation methods. Six ligation methods (regular uncoated, slick [coated], conventional silver, easy-to-tie, silicone-impregnated,

and standard silvermodules) were used with standard stainless steel brackets and 0.019 x 0.025-in archwires, and resistance to movement was measured. There was no significant difference between the frictional resistance of brackets ligated with regular uncoated, silicone-impregnated, and easy-to-tie modules. The frictional properties of coated modules were not significantly affected by repeating the test 5 times or by storage in saliva for a week.

Lorenzo Franchi and Tiziano Baccetti⁷⁸ (2006) compared the forces generated by new nonconventional elastomeric ligatures (NCEL) and conventional elastomeric ligatures (CEL) during leveling and aligning phases. They concluded that when a slight amount of tooth alignment was needed (1.5 mm), the differences in the performance of the CEL and NCEL were minimal, but these differences become extremely significant when correction of a misalignment of more than 3 mm was attempted. However, in their study, only the size of the conventional ligatures employed was specified (inside diameter of 1.3 mm and thickness of 0.9 mm) not the size of the low-friction ligatures. In addition, only round archwires were considered.

Camporesi et al¹¹ (2007), using the **Franchi and Baccetti⁷⁸** model, evaluated the frictional force generated by preadjusted 0.022-in ceramic brackets with low-friction esthetic ligatures and confirmed what had been found with metal brackets in 2006.

Daniel J. Rinchuse and Peter G. Miles¹⁷ (2007) reviewed the literature regarding self ligating brackets and concluded that as a generalization, self-ligating brackets show excellent performance in vitro with smaller wires that

are used early in treatment. However, when larger wires are used, no differences were found between self-ligating brackets and conventional brackets. They also pointed both passive and active self ligating brackets press against the wire to some extent throughout treatment, making both designs interactive.

Tecco S et al¹¹⁸ (2007) compared the forces released during sliding mechanics with passive self-ligating brackets or nonconventional elastomeric ligatures. They concluded that when loosened steel ligatures are used, the friction of conventional and self-ligating brackets is more or less similar.

Bacetti T et al⁵ (2008) showed that the combination of the low-friction ligatures with the super elastic nickel-titanium wires produced a significantly smaller amount of binding at the bracket/archwire/ligature unit when compared to conventional elastomeric ligatures. They concluded that the biomechanical consequences of the use of low-friction ligatures were of shorter duration in orthodontic treatment during the leveling and aligning phase.

Franchi et al⁷⁷ (2008) compared the frictional forces generated by active and passive self-ligating brackets, conventional elastomeric ligatures, and nonconventional elastic ligatures (Leone) at the 0.019 x 0.025-in SS wire size. They concluded that there are no significant differences between the friction generated by self ligating brackets and nonconventional elastic ligature, and that both produced significantly less friction than conventional elastomeric ligatures.

Paola Gandini et al⁹¹ (2008) compared the frictional forces produced by a passive self-ligating bracket (SLB) in vitro and a conventional bracket (CB) used with two types of elastomeric ligatures. The brackets, wires and ligation methods used in vitro were a passive SLB and a CB used with two types of elastomeric ligatures (conventional elastomeric ligature [CEL] and unconventional elastomeric ligatures [UEL]). Resistance to sliding of the bracket/wire/ligature systems was measured with an experimental model mounted on the crosshead of an Instron testing machine. UELs are able to produce significantly lower levels of frictional forces than CEL when applied on CB; thus, UELs may represent a valid alternative to passive self-ligating brackets for low-friction biomechanics.

Thaís Gelatti Bortoly, Ariana Pulido Guerrero et al¹¹⁹ (2008) evaluated in vitro properties related to sliding resistance of esthetic ligatures. The frictional force of 6 ligatures was investigated: 5 esthetic and 1 stainless steel as controls. Friction was studied by sliding a 0.019 x 0.025-in stainless steel archwire through the slot of stainless steel maxillary premolar brackets 0.022-in with a Roth prescription. Stainless steel brackets and archwires were used because they have the lowest influence of frictional resistance. The specimens were prepared by bonding bracket on a clear acrylic block. They concluded that the superficial characteristics of elastomeric ligatures had no advantage in the frictional force they produced.

Burrow SJ⁹ (2009) found that the frictional resistance and subsequent stick-slip behavior at the interfaces between the bracket and archwire, as the attached

tooth moves by tipping and uprighting, are dictated by the magnitudes of forces normal to the surfaces involved. These normal forces are due to ligation and tipping moments.

Simona Tecco, Stefano Tete, Felice Festa¹¹⁰ (2009) compared FR generated by various archwires coupled with small, medium, or large low-friction ligatures or with conventional ligatures. Their findings indicate that the design of low friction ligatures allows low friction only when they are coupled with round archwires and not when they are coupled with the most rectangular archwires.

Lima et al⁷⁵ (2010) did a study of frictional forces in stainless steel and plastic brackets using four types of wire ligation. Four stainless steel and four polycarbonate composite brackets were placed in a universal testing machine for the traction of a piece of 0.019 x 0.025-in wire at 0.5 mm/min and total displacement of 8 mm. Ligations were performed according to the following alternatives: metal ligation with Steiner tying pliers; metal ligation using Mathieu tying pliers; Morelli elastomeric ligation; and TP Orthodontics elastomeric ligation. They concluded that elastomeric modules generated more friction than the metal ligations, and the ligation with the Mathieu tying pliers caused less friction than all the other conditions under study.

Sonia Kahlon et al⁵⁴ (2010) compared frictional resistance with 5 ligation methods. They test the frictional forces by drawing 2 sizes of rectangular SS wires with 5 ligation systems in maxillary right second premolar brackets. The results of their study showed that both self-ligating brackets and the Leone

slide ligature produced significantly less friction than conventional elastomeric modules. They concluded that an increase in wire size led to an increase in friction in all bracket-archwire combinations. The Leone slide ligature produced less friction than did conventional elastomeric ligatures.

Natalie Reznikov et al⁸³ 2010 assessed the friction forces between various self-ligating brackets and stainless steel orthodontic wires, subjected to different shear and bending forces in the buccolingual plane. They showed that a stiff clip resists wire deflection and relays a higher force back onto the wire as a component of the normal force. They confirmed the hypothesis that wire deflection and shear forces play a dominant role in high-modulus materials. They concluded that self-ligating brackets have considerable friction resistance in nonzero deflections of stainless steel wire in the buccolingual plane. The degree of friction resistance is proportional to the grade of the wire-securing element's rigidity and to the extent of the wire deflection.

Christa L. Oliver et al¹⁴ 2011 compare the frictional resistance of six self-ligating bracket systems, while sliding on rectangular stainless steel archwires of three different dimensions under dry conditions. They concluded that an increase in wire dimension did not significantly influence the sliding behavior of the passive self-ligating brackets. However, the active and interactive self-ligating brackets appeared to be affected only by the change in wire depth (buccolingual dimension) and not by the change in wire height.

MATERIALS AND METHODS

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MATERIALS

Brackets (Fig 1)

90 Stainless steel mandibular brackets with 0.022-in slot in Roth prescription with 0° tip and 0° torque (Gemini series 3M Unitek Monrovia, Calif) were used.

Wires (Fig 2)

90 stainless steel wire specimen of 8cm in length with 0.019X0.025” dimension (3M Unitek, Monrovia, CA U.S) cut from straight lengths were used.

Modes of ligation (Fig 3)

Stainless steel (SS) ligature wire 0.010-in (3M Unitek Monrovia, Calif),

Clear elastomeric modules (3M Unitek Monrovia, Calif) and

Clear super -slick modules were used (TP Orthodontics, LaPorte, India; USA) .

Test Solutions (Fig 4)

1) Artificial saliva (control solution) containing methyl cellulose 0.5% w/v and glycerin 30% w/v per 5 ml of solution, pH of 7 (ICPA health products LTD. 286/287 GIDC. Ankleshwar).

2) Colgate Phos -Flur mouth rinse (1.23% sodium fluoride acidulated phosphate; 0.04% w/v sodium fluoride) pH of 5.1 (Vita Biopharma Pvt . Ltd, Daman, India) .

Testing apparatus (Fig 5)

Friction-testing device-Autograph AG-IS Shimadzu Precision Universal Tester, Shimadzu, Japan , load cell, signal amplifier, and computer.

Other instruments used in this study (Fig 6 and 7).

- i. Bracket holder.
- ii. Orthodontic cutter (Heavy duty) .
- iii. Mathieu forceps.
- iv. Mosquito forceps,
- v. Tweezer
- vi. Clear acrylic plates and Scale
- vii . Multi marking pens (Black and Red
- viii. Fevikwik.

METHODOLOGY

Custom made templates made of acrylic with dimension 4 “ x 2 ” x 1 ” to measure the resistance to sliding were prepared . Horizontal and vertical reference lines were scribed on these template with commercially available permanent markers (Red Multimark pen FABER-CASTELL). Vertical lines were marked almost at the center parallel to the long axis of the template. Horizontal lines were marked perpendicular to the vertical line just 1 cm off the lower end of the template (Fig.8). 90 templates of this type were prepared. Mandibular central incisor brackets in Roth prescription were fixed on to this template using industrial adhesive (Fevikwik) with the center of the bracket placed at the junction of horizontal and vertical lines and bracket wings oriented parallel to the horizontal lines.

Total 90 templates with mounted brackets and 90 wire segments were divided into 3 major groups as group A, group B and group C. Each group consisted of 30 SS brackets and 30 SS wire segments. The brackets and archwires were cleaned with alcohol wipes. In group A, elastomeric modules were used to engage 0.019 x 0.025" stainless steel wire segments with brackets using mosquito forceps. In group B SS ligatures were used for ligation using Mathieu forceps. In order to standardize the ligation force of stainless steel, ligatures were initially fully tightened and then unwound by 3 turns as suggested by **Max Hain et al**³⁸ (2003). Loose ligation was checked by rocking the ligature to confirm that there was a little play between both spans of the ligature and the archwire. The end of the ligature was then tucked in over the archwire. In Group C, Super slick modules were used for ligation with mosquito forceps. All ligations were carried out with SS wire projecting 25 mm from the lower end of the template, to form a test unit (Fig. 9).

Each sample group was tested under 3 conditions – dry, wet by immersed in artificial saliva and soaked in the fluoride mouthwash. All testings were carried out at room temperature. Testing apparatus consisted of Autograph AG-IS Shimadzu Precision Universal Tester, Shimadzu, Japan which is connected to an amplifier and a computer monitor from which the testing values were displayed in the form of digital readout. Precision Universal Tester consists of one upper and lower member. The bracket -wire assembly along with the mounting template were engaged on the testing apparatus. The lower member holds the mounting template in place while the upper member

was used to tightly hold the wire segment which was projecting beyond the template from the lower end. The upper member was used to pull the wire segments through the brackets during testing (Fig 10). On the machine, tensile mode was selected and a load was adjusted to 5 Newtons to pull the wire segments with a crosshead speed of 20 mm/ min through a distance of 5mm.

All bracket wire assembly was first tested under dry condition and friction were recorded . Under wet conditions, all samples were soaked in artificial saliva containing methyl cellulose 0.5% w/v and glycerin 30% w/v per 5 ml of solution with a pH of 7 for 10 minutes (Fig.11). Friction tests were carried out again for each sample groups. After that all sample groups were immersed in commercially available fluoride mouth rinse containing 1.23% sodium fluoride acidulated phosphate; 0.04% w/v sodium fluoride with a pH of 5.1 for 90 minutes, approximating 3 months of 1-minute daily topical fluoride treatments and tests were conducted(Fig.12) .

The force required to pull the wire through the bracket mounting assembly were recorded, amplified and displayed on the computer monitor as a graphical representation. In the graph not only the tensile force delivered but also the distance the wire segments moved were displayed. The force required to initiate the sliding (STATIC FORCE) was greater which was represented as a peak in the initial part of each graph. This peak which is the highest force required before any movement was initiated represents the static friction force for each sample.

STATISTICAL ANALYSIS

The data obtained were evaluated to compare the resistance to sliding in relation to

- a) three methods of ligation and
- b) three environmental conditions.

The qualitative analysis of the data tabulated were analyzed for statistical significance using statistical package SPSS software (version17, SPSS, Chicago). The significant differences among and between three methods of ligation under three environmental conditions for resistance to sliding were calculated. The mean, standard deviation and standard error were calculated for each method of ligation under each environmental condition. The mean values obtained were compared by using one-way ANOVA test. Multiple comparison of means was done using Post -Hoc test and Tukey HSD test. In the present study P value of <0.05 was considered as the level of significance and <0.01 as level of high significance.

Colour plates

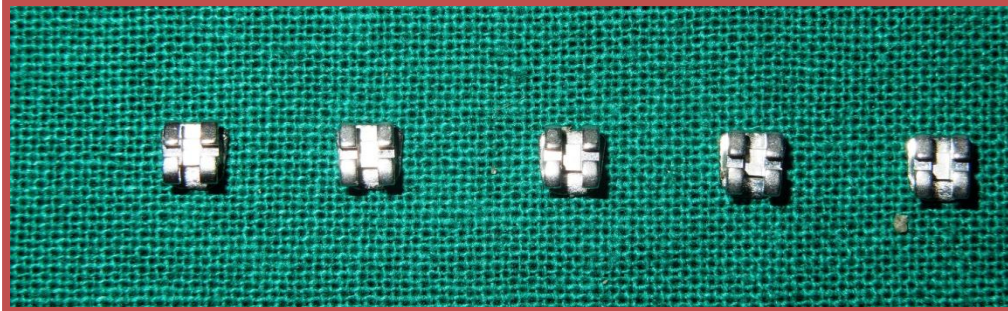


Fig 1: Preadjusted edgewise brackets used in this study.

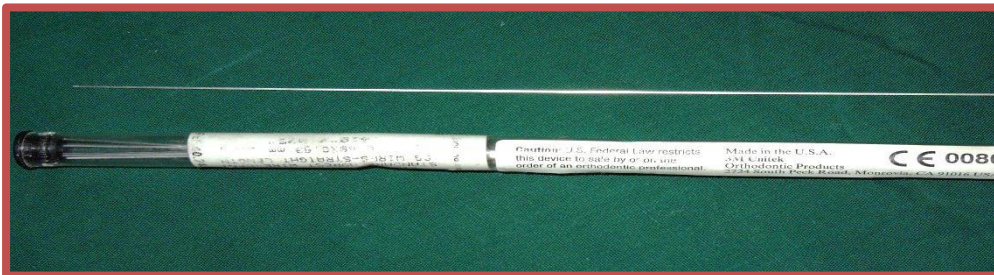


Fig 2: 0.019x0.025" SS wire used in this study.



Fig 3: Various ligatures used in this study.



Fig 4: Solutions used in this study - Wet Mouth (artificial saliva) and Phos-Flur(fluoride mouth rinse)



Fig 5: Precision Universal Tester, Shimadzu, Japan



Fig 6: Armamentarium used in this study.



Fig 7: Armamentarium used to prepare mounting template

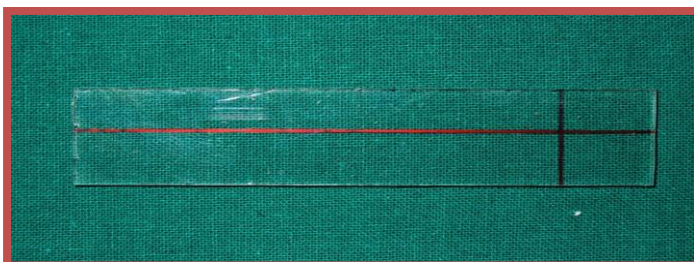


Fig 8: Mounting template after orientation lines were scribed

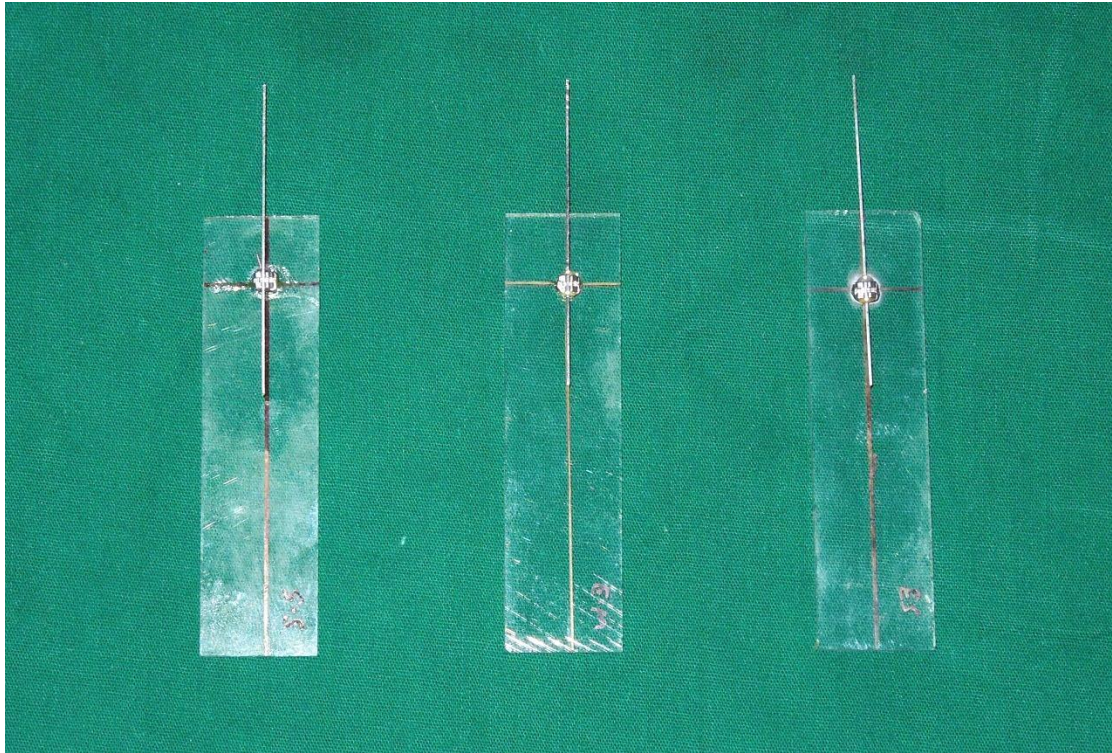


Fig 9: Mounting templates with brackets attached to it



Fig 10(a): Testing machine with mounting template engaged on it- frontal view

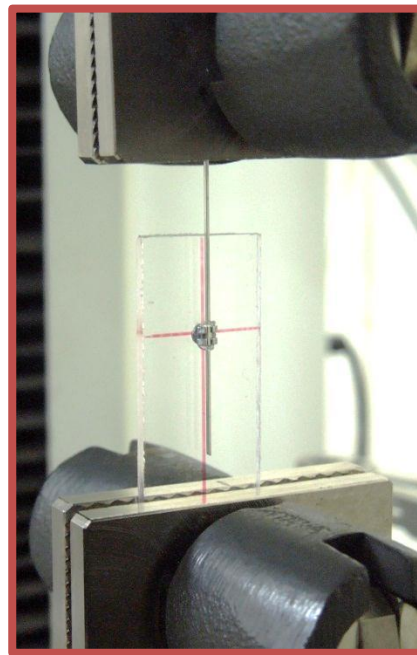


Fig 10(b): Testing machine with mounting template engaged on it- close up of lateral view

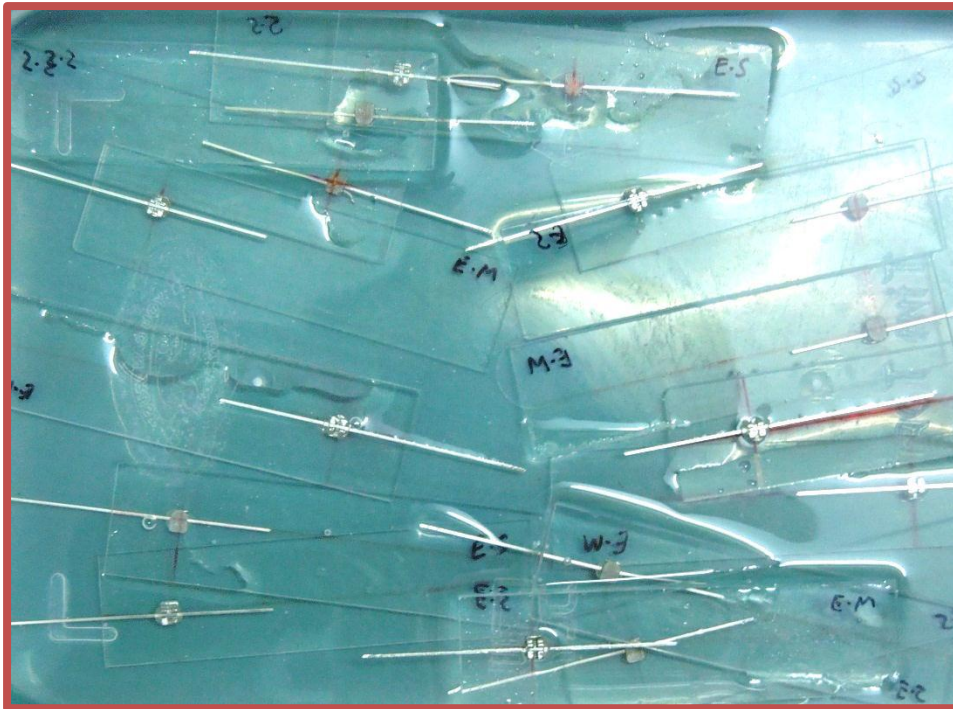


Fig 11: Samples immersed in artificial saliva for 10 minutes.

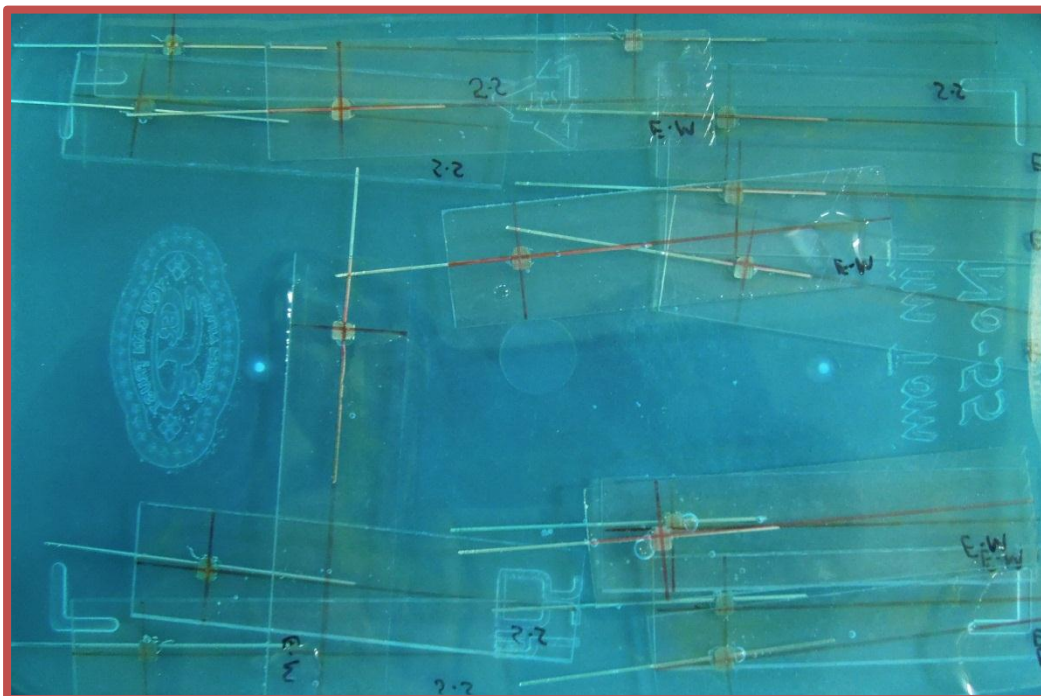


Fig 12: Samples soaked in fluoride in mouth rinse .

RESULTS

RESULTS

Resistance to sliding of 0.019 x 0.025” SS wire on SS brackets using three ligation methods under three environmental conditions were evaluated. Tests were conducted on Precision Universal Testing Machine, Shimadzu, Japan. The force required for sliding of the arch wire were recorded in the computer as a graphical representation. In the graph force elevates to a peak in the beginning and then dips down. The peak of the graph which represents the highest force to initiate the sliding movements (static friction) were taken.

Three types of ligation methods were compared under three environmental conditions. The mean, standard deviation, standard error and significance between groups were calculated using One Way ANOVA descriptive statistics. The significance among various environmental conditions and ligation methods were analyzed using Tukey HSD and Post Hoc tests.

The frictional resistance to sliding using elastomeric modules as ligation under three environmental conditions were measured and values tabulated (Tables 1 and 2).

Table 1: ONEWAY, ANOVA to compare the frictional force using elastomeric modules as ligation under three environmental conditions.

	N	Mean	Std. Deviation	Std. Error	Sig. between groups
Dry	30	.986993	.1071609	.0195648	.000*** (S)
Wet	30	1.063657	.1062004	.0193895	
After Fluoride Application	30	1.265783	.1569087	.0286475	
Total	90	1.092144	.1815976	.0191421	

***** P < 0.001, S-HIGHLY SIGNIFICANT**

Table 2: Post Hoc Tests, multiple Comparisons to evaluate significance among three environmental conditions using elastomeric modules as ligation.

(I) Environmental Condition	(J) Environmental Condition	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Dry	Wet	-.116663	.032449	.150	-.194037	-.039289
	After Fluoride Application	-.318790(*)	.032449	.000*** (S)	-.396164	-.241416
Wet	Dry	.116663	.032449	.150	.039289	.194037
	After Fluoride Application	-.202127(*)	.032449	.000*** (S)	-.279501	-.124753
After Fluoride Application	Dry	.318790(*)	.032449	.000*** (S)	.241416	.396164
	Wet	.202127(*)	.032449	.000*** (S)	.124753	.279501

*** The mean difference is significant at the .05 level.**

****P< 0.05 significant at 0.05 level**

***** P <0.001 , S- HIGHLY SIGNIFICANT**

The results obtained showed that the mean friction values obtained under wet condition (1.063657) using artificial saliva was higher than that under dry condition (0.986993). But even though mean friction value was higher under wet condition than dry condition, statistical analysis showed no significant difference between these two conditions. The mean frictional values obtained after fluoride application (1.265783) was higher than that obtained under wet condition (1.063657) with a significance at the 0% level. The mean frictional values obtained after fluoride application (1.265783) which in turn was higher than that obtained under dry condition (0.986993) with a significance at 0% level.

Results

The frictional resistance to sliding using stainless steel ligation under three environmental conditions were measured and values tabulated (Tables 3 and 4).

Table 3: ONEWAY, ANOVA to compare the frictional force using stainless steel ligation under three environmental conditions.

	N	Mean	Std. Deviation	Std. Error	Sig. between groups
Dry	30	.921447	.2245589	.0409987	.000*** (S)
Wet	30	.982780	.3044085	.0555771	
After Fluoride Application	30	1.205583	.2353873	.0429757	
Total	90	1.036603	.2824018	.0297678	

*** $P < 0.001$, S-HIGHLY SIGNIFICANT

Table 4: Post Hoc Tests, multiple Comparisons to evaluate significance among three environmental condition using stainless steel ligation.

(I) Environmental Condition	(J) Environmental Condition	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Dry	Wet	-.061333	.0664159	.627	-.219701	.097034
	After Fluoride Application	-.284137 (*)	.0664159	.000*** (S)	-.442504	-.125769
Wet	Dry	.061333	.0664159	.627	-.097034	.219701
	After Fluoride Application	-.222803 (*)	.0664159	.003**	-.381171	-.064436
After Fluoride Application	Dry	.284137 (*)	.0664159	.000*** (S)	.125769	.442504
	Wet	.222803 (*)	.0664159	.003**	.064436	.381171

* The mean difference is significant at the .05 level.

** $P < 0.05$ significant at 0.05 level

*** $P < 0.001$, S- HIGHLY SIGNIFICANT

The results obtained showed that mean friction under wet condition (0.982780) was higher than the values obtained under dry condition (0.921447). But even though mean friction value was higher under wet condition than dry condition, statistical analysis showed no significant

difference between these two conditions. The mean friction after fluoride application (1.205583) was higher than that under wet condition (0.982780) with a significance level of 3%. The magnitude of friction after fluoride application (1.205583) was more than that under dry condition (0.921447) with a level of significance at 0%. The standard deviation obtained when stainless steel ligatures were used was much higher than the standard deviation in other ligation methods showing large operator variability in the force which hold the wire against the bracket wall when SS ligation was used .

The frictional resistance to sliding using Super Slick as ligation under three environmental conditions were measured and values tabulated (Tables 5 and 6).

Table 5: ONEWAY, ANOVA to compare the frictional force using Super Slick ligation under three environmental condition.

	N	Mean	Std. Deviation	Std. Error	Sig. between groups
Dry	30	.825470	.0657037	.0119958	.001*** (S)
Wet	30	.841580	.0468680	.0085569	
After Fluoride Application	30	.897147	.1024465	.0187041	
Total	90	.854732	.0805950	.0084955	

*** $P < 0.001$, S-HIGHLY SIGNIFICANT

Table 6: Post Hoc Tests, multiple Comparisons to evaluate significance among three condition using Super Slick ligation.

(I) Environmental Condition	(J) Environmental Condition	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Dry	Wet	-.016110	.0194416	.686	-.062468	.030248
	After Fluoride Application	-.071677(*)	.0194416	.001 *** (S)	-.118035	-.025319
Wet	Dry	.016110	.0194416	.686	-.030248	.062468
	After Fluoride Application	-.055567(*)	.0194416	.015**	-.101925	-.009209
After Fluoride Application	Dry	.071677(*)	.0194416	.001 *** (S)	.025319	.118035
	Wet	.055567(*)	.0194416	.015**	.009209	.101925

* The mean difference is significant at the .05 level.

**P< 0.05 - significant at 0.05 level

*** P <0.001 , S- HIGHLY SIGNIFICANT

The results obtained showed that mean friction under wet condition (0.841580) was higher than the values obtained under dry condition (0.825470). But even though mean friction value was higher under wet condition than dry condition, statistical analysis shows no significant difference between these two conditions. The mean friction after fluoride application (0.897147) was higher than that under wet condition (0.841580) with a significance level of 1.5%. The magnitude of friction after fluoride application (0.897147) was more than that under dry condition (0.825470) with a level of significance at 0.1%.

The frictional resistance to sliding under dry condition using three methods of ligation were measured and values tabulated (Tables 7 and 8).

Table 7: ONEWAY, ANOVA to compare the frictional force under dry condition for three different ligation methods.

	N	Mean	Std. Deviation	Std. Error	Sig. between groups
Elastomeric Module	30	.986993	.1071609	.0195648	.005**
Stainless Steel	30	.921447	.2245589	.0409987	
Superslick	30	.825470	.0657037	.0119958	
Total	90	.897970	.1560361	.0164477	

****P < 0.05 - significant at 0.05 level**

Table 8: Post Hoc Tests, multiple Comparisons to evaluate significance among three ligation under dry condition.

(I) Method of Ligation	(J) Method of Ligation	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Elastomeric Module	Stainless Steel	.025547	.0383629	.784	-.065929	.117022
	Superslick	.121523(*)	.0383629	.006**	.030048	.212999
Stainless Steel	Elastomeric Module	-.025547	.0383629	.784	-.117022	.065929
	Superslick	.095977(*)	.0383629	.037**	.004501	.187452
Superslick	Elastomeric Module	-.121523(*)	.0383629	.006**	-.212999	-.030048
	Stainless Steel	-.095977(*)	.0383629	.037**	-.187452	-.004501

* The mean difference is significant at the .05 level.

**P < 0.05 - significant at 0.05 level

*** P < 0.001 , S- HIGHLY SIGNIFICANT

The results obtained showed that mean friction with stainless steel ligation (0.921447) was lower than elastomeric ligation (.986993). Even though mean friction value was higher with elastomeric ligation than stainless steel ligation (0.921447), statistical analysis showed no significant difference between these two groups. The mean value of friction with Superslick (0.825470) as ligation was considerably lower than elastomeric ligation (.946993) with a significance at the 0.6% level. Magnitude of friction using Superslick (0.825470) as ligation

was lower than that using stainless steel (0.921447) as ligation with a significance at 3.7% level.

The frictional resistance to sliding under wet condition using three methods of ligation were measured and values tabulated (Tables 9 and 10).

Table 9: ONEWAY, ANOVA to compare the frictional force under wet condition for three different ligation methods.

	N	Mean	Std. Deviation	Std. Error	Sig. between groups
Elastomeric Module	30	1.063657	.1062004	.0193895	.000*** (S)
Stainless Steel	30	.982780	.3044085	.0555771	
Superslick	30	.841580	.0468680	.0085569	
Total	90	.962672	.2076085	.0218839	

*** $P < 0.001$, S-HIGHLY SIGNIFICANT

Table 10: Post Hoc Tests, multiple Comparisons to evaluate significance among three ligation methods under wet condition.

(I) Method of Ligation	(J) Method of Ligation	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Elastomeric Module	Stainless Steel	.080877	.0485660	.224	-.034928	.196681
	Superslick	.222077(*)	.0485660	.000*** (S)	.106272	.337881
Stainless Steel	Elastomeric Module	-.080877	.0485660	.224	-.196681	.034928
	Superslick	.141200(*)	.0485660	.013**	.025395	.257005
Superslick	Elastomeric Module	-.222077(*)	.0485660	.000*** (S)	-.337881	-.106272
	Stainless Steel	-.141200(*)	.0485660	.013**	-.257005	-.025395

* The mean difference is significant at the .05 level.

** $P < 0.05$ - significant at 0.05 level

*** $P < 0.001$, S- HIGHLY SIGNIFICANT.

The results obtained showed that mean friction with stainless steel ligation (.982780) was lower than elastomeric ligation (1.063657). Even though mean

friction value was higher with elastomeric ligation than stainless steel ligation, statistical analysis showed no significant difference between these two groups. The mean value of friction with Superslick (0.841580) as ligation was considerably lower than elastomeric ligation (1.063657) with a significance at the 0% level. Magnitude of friction using Superslick (0.841580) as ligation was lower than that using stainless steel (.982780) as ligation with a significance at 1.3% level.

The frictional resistance to sliding using three methods of ligation after fluoride mouth rinse application were measured and values tabulated (Tables 11 and 12).

Table 11: ONEWAY, ANOVA to compare the frictional forces after application of fluoride mouth rinse with three different ligation methods.

	N	Mean	Std. Deviation	Std. Error	Sig. between groups
Elastomeric Module	30	1.265783	.1569087	.0286475	.000*** (S)
Stainless Steel	30	1.205583	.2353873	.0429757	
Superslick	30	.897147	.1024465	.0187041	
Total	90	1.122838	.2363501	.0249135	

***** P < 0.001, S-HIGHLY SIGNIFICANT**

Table 12: Post Hoc Tests, multiple comparisons to evaluate significance among three ligation after fluoride application.

(I) Method of Ligation	(J) Method of Ligation	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Elastomeric Module	Stainless Steel	.060200	.0448511	.376	-.046746	.167146
	Superslick	.368637(*)	.0448511	.000*** (S)	.261690	.475583
Stainless Steel	Elastomeric Module	-.060200	.0448511	.376	-.167146	.046746
	Superslick	.308437(*)	.0448511	.000*** (S)	.201490	.415383
Superslick	Elastomeric Module	-.368637(*)	.0448511	.000*** (S)	-.475583	-.261690
	Stainless Steel	-.308437(*)	.0448511	.000*** (S)	-.415383	-.201490

*** The mean difference is significant at the .05 level.**

****P< 0.05 - significant at 0.05 level**

***** P <0.001 , S- HIGHLY SIGNIFICANT**

The results obtained showed that mean friction with stainless steel ligation (1.205583) was lower than elastomeric ligation (1.265783). Even though mean friction value is higher with elastomeric ligation than stainless steel ligation, statistical analysis showed no significant difference between these two groups. The mean value of friction with Superslick (0.897147) as ligation was considerably lower than elastomeric ligation (1.265783) with a significance at the 0% level. Magnitude of friction using Superslick (0.897147) as ligation was lower than that using stainless steel (1.205583) as ligation with a significance at 0%level.

Chart 1 :Comparison of mean static frictional resistance using elastomeric modules as ligation under three environmental condition

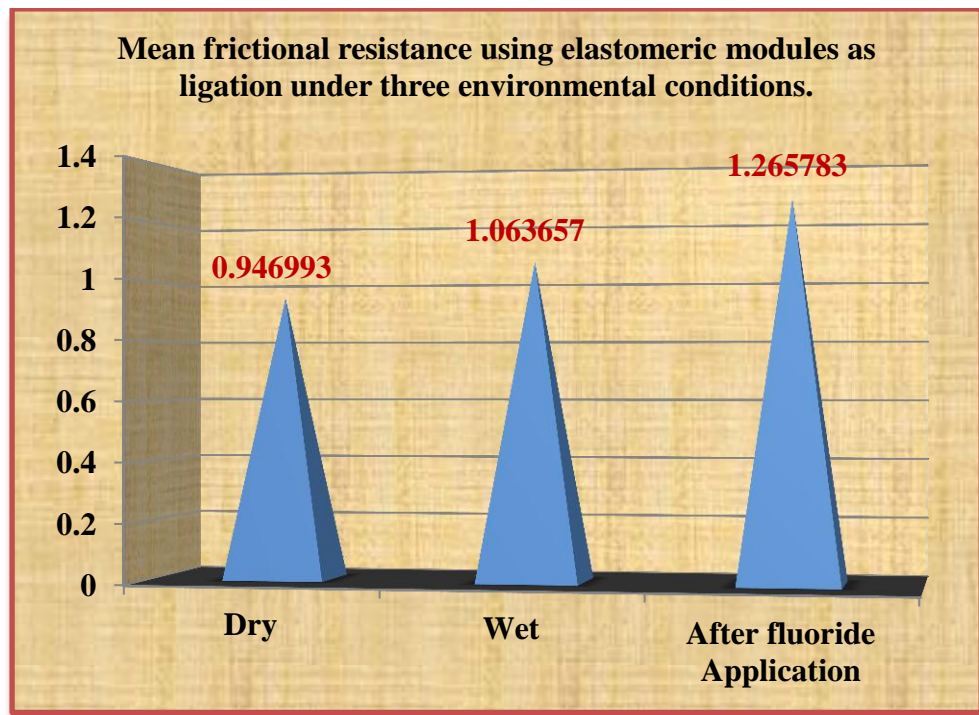


Chart -2 :Comparison of mean static frictional resistance using stainless steel as ligation under three environmental condition

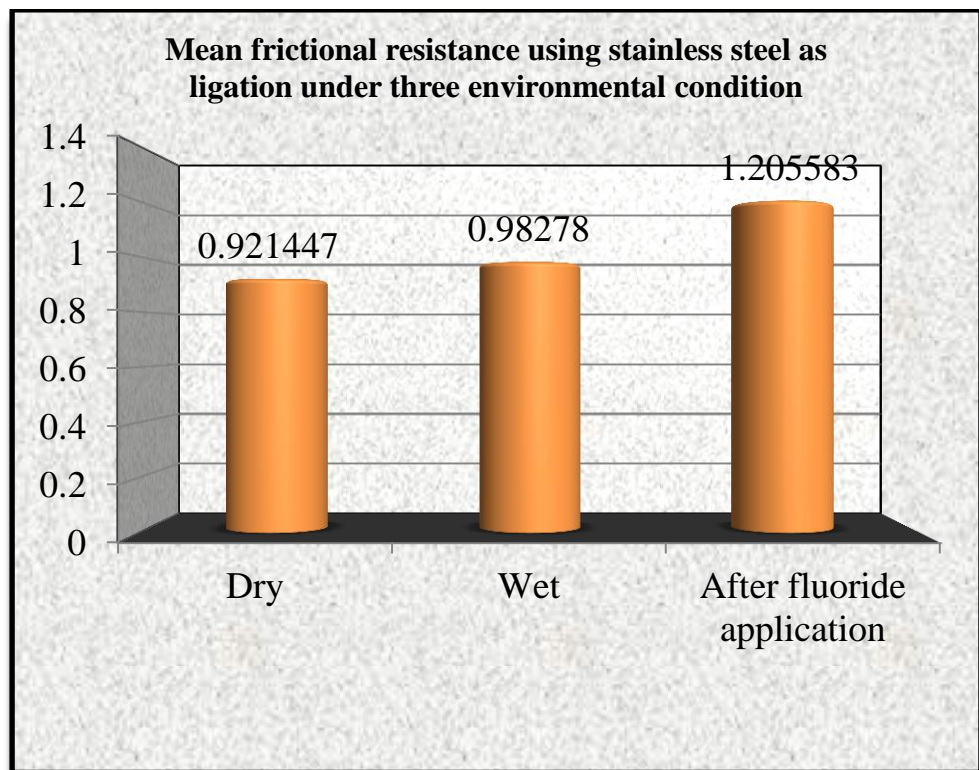


Chart-3: Comparison of mean static frictional resistance using super slick as ligation under three environmental conditions

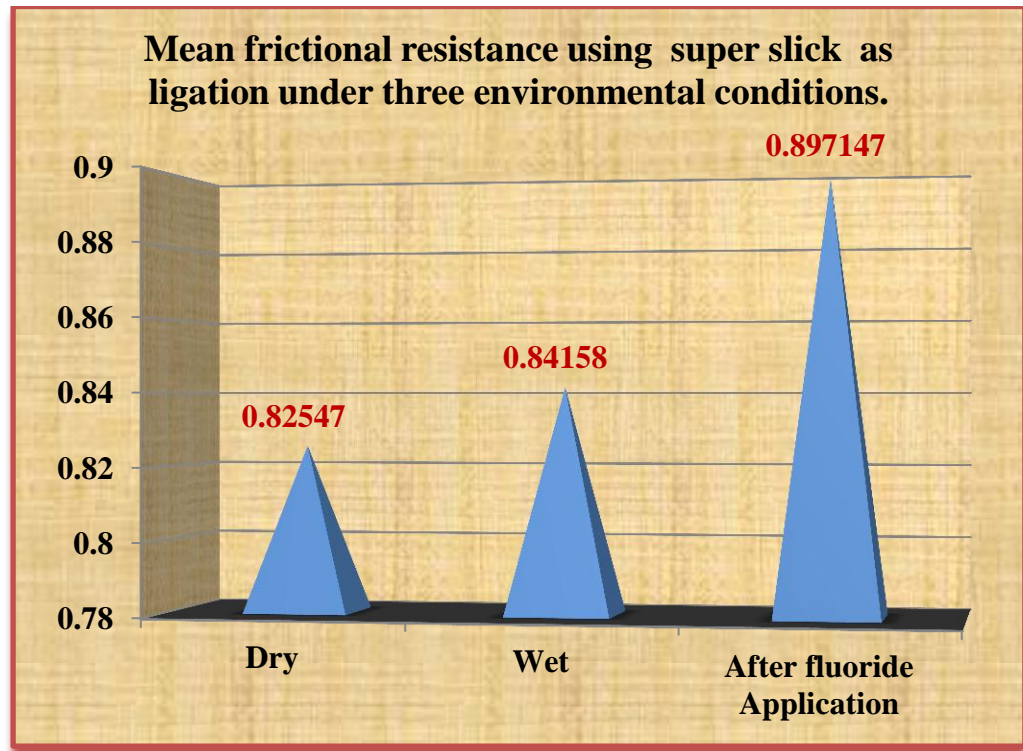


Chart -4: Comparison of mean static friction resistance under dry condition using three methods of ligation

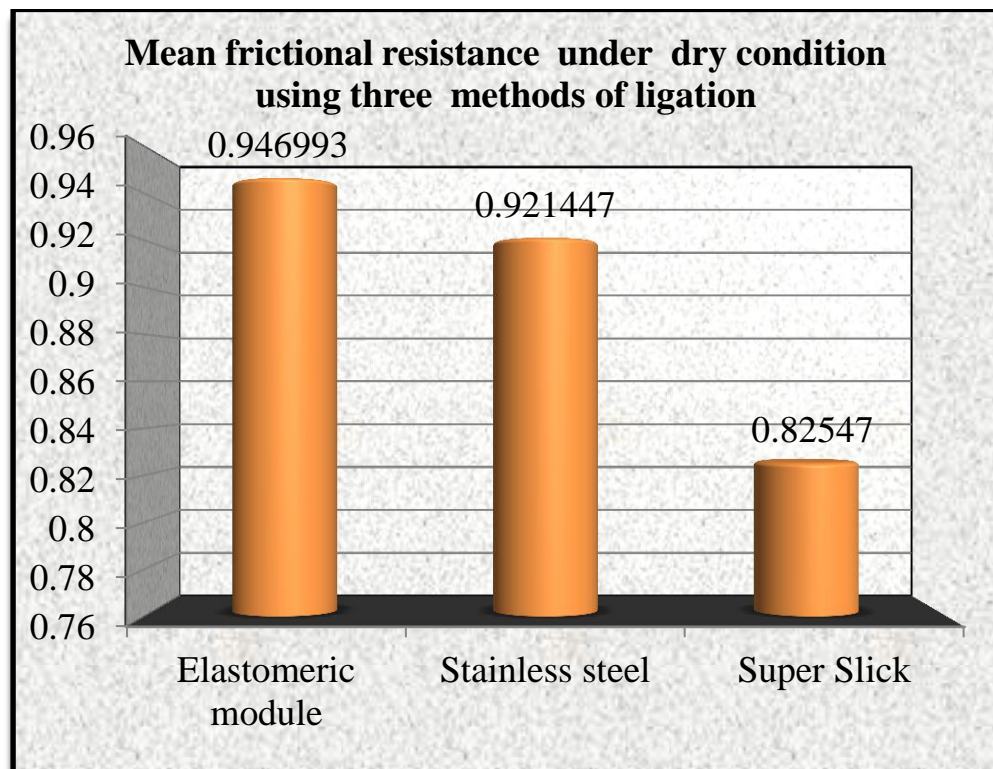


Chart -5: Comparison of mean static friction resistance under wet condition using three methods of ligation

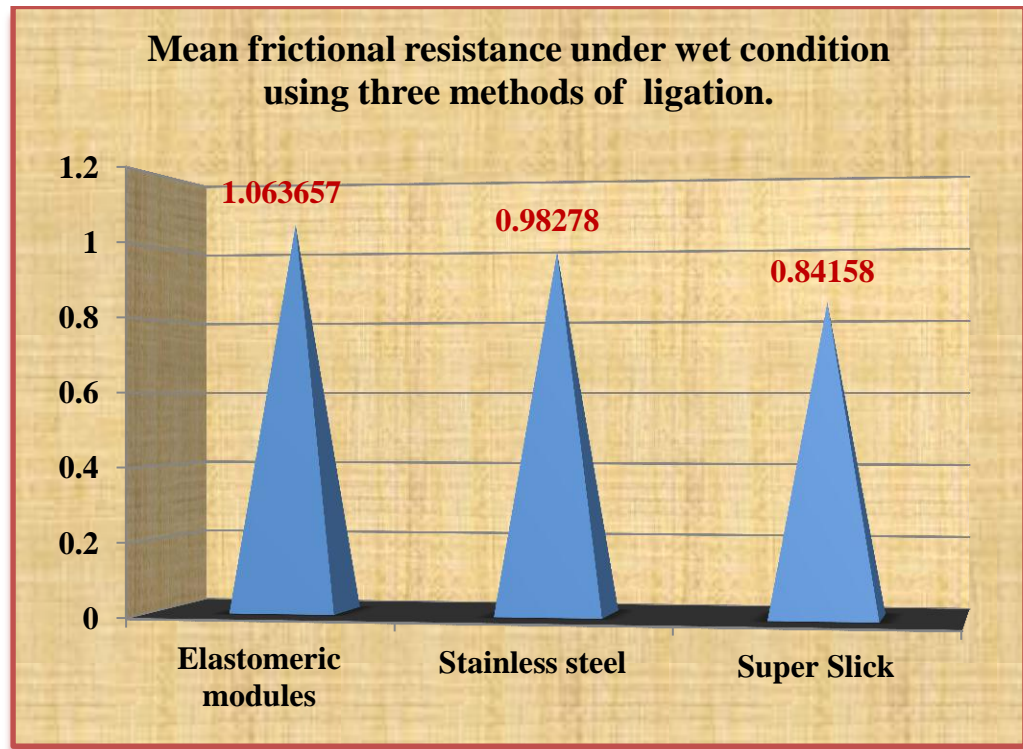
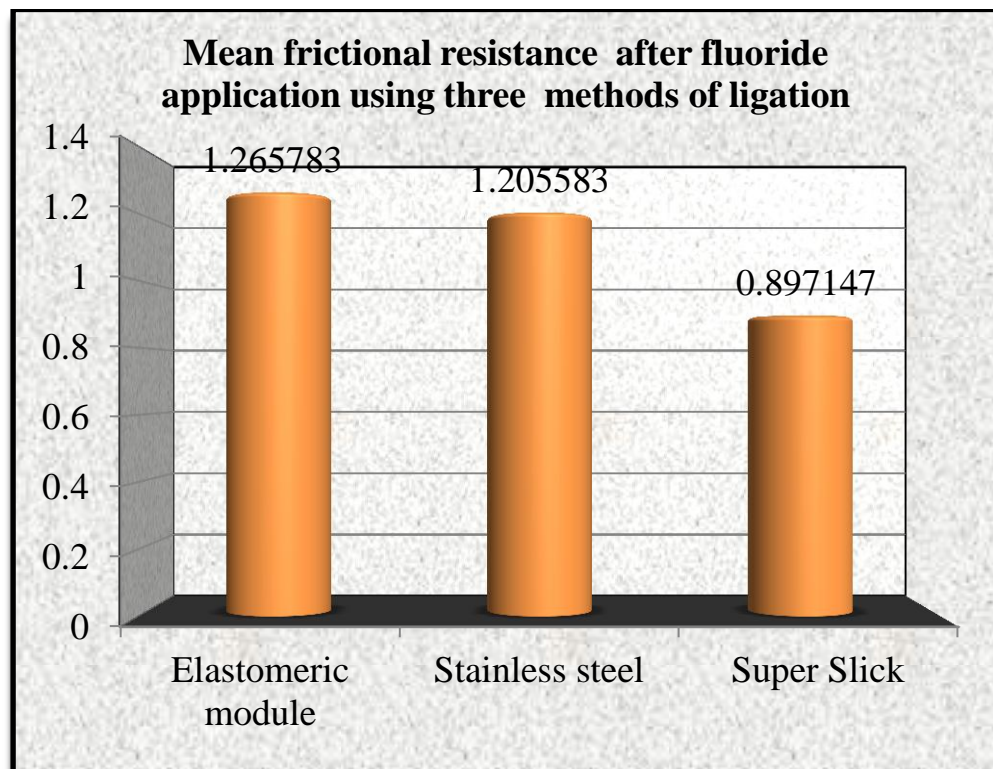


Chart- 6: Comparison of mean static frictional resistance after fluoride application using three different methods of ligation



DISCUSSION

Discussion

Friction, according to 'The Encyclopedia of Physics, 3rd edition' ⁹⁹, is the resistance to motion when one object moves tangentially against another. It's direction of action is parallel and opposite to the direction of sliding²⁷. The maximum magnitude of friction is hypothesized to be proportional to a normal force; the constant is termed the coefficient of friction. The coefficient of friction for a given material surface is a constant, which may be dependent on the roughness, texture, or hardness of the surfaces⁹⁹. There are two types of coefficient of friction: static and kinetic. For all practical purposes, kinetic friction is irrelevant in orthodontic tooth movement because continuous motion along an archwire rarely if ever occurs⁹. In sliding mechanics, we are dealing with a quasi-static thermodynamic process, which means that the process happens slowly and goes through a sequence of states that are close to equilibrium⁹.

One of the major factor determining success of the orthodontic treatment is the precise control of the tooth to be moved and the tooth opposing the movement which is the anchor tooth. For having a better control over the tooth movement, only optimum amount of force will be directed towards the root of the tooth intended to move, so that maximum cellular response will be evoked and minimum or little force exerted on to the anchor tooth. In order to shorten the treatment time and to avoid unwanted side effects, desired movement of tooth to occur in a relatively smooth path with minimum reactionary forces. In orthodontics, major factor involved in determining the above mentioned

factors is friction. Even though friction is mainly involved in sliding mechanics for space closure, it also plays a considerable role in initial alignment phase. The amount of wire engaged in malaligned tooth will be more than the wire required to engage well aligned tooth⁹⁵. The wire has to slide through the brackets and buccal tube during the alignment phase. So the friction between arch wire and bracket can considerably reduce the amount of tooth movements and can produce untoward force on to the anchor tooth which in turn produce unwanted movement of the teeth. This led orthodontists to research on developing systems with least resistance to sliding.

Resistance to sliding (RS) can be divided into 3 components⁷¹:

(1) Friction, static or kinetic

(2) Binding (BI), created when the tooth tips or the wire flexes so that there is contact between the wire and the corners of the bracket

(3) Notching (NO),

The contributions of friction, binding, and notching to resistance to sliding can be understood best by considering the 3 stages in the active phase of moving teeth⁹.

(1) The first is the early stage of sliding as the tooth tips and contact of the wire with the corner of the bracket begins to occur; both friction and binding contribute to resistance to sliding: Resistance to sliding, (RS) = Classical friction, (FR) + Binding, (BI).

(2) In stage 2, the contact angle increases between the bracket and the wire, when binding is the major source of resistance and friction becomes inconsequential.

(3) In stage 3, if the contact angle becomes steep enough, notching of the wire occurs, and both friction and binding become negligible: RS =NO.

Several variables have been found to affect the levels of friction between the bracket and wire⁸². These variables may be either mechanical or biological. Mechanical variables include bracket material, slot size, bracket width^{28,21} and angulation, wire shapes, wire size and wire material^{121,66,68,123,56,28}, the ligature material and force of ligation. Biologic factors that affect bracket-wire friction are saliva, plaque, acquired pellicle, and corrosion⁷⁵.

Brackets serve as a handle through which forces will be delivered from archwire to the tooth. Three types of brackets are presently available for bonding: plastic based, ceramic based, and metal (e.g., stainless steel, gold-coated, titanium) based³⁷. Metallic orthodontic brackets have demonstrated properties that are closer to the ideal, and have been used most frequently for fixed orthodontic treatment. Since the introduction of Stainless steel, it has remained the most widely used material in the manufacture of orthodontic attachments. The advantage of SS is primarily its low cost, greater strength, higher modulus of elasticity, good formability and high corrosion resistance in the mouth³⁷. In this study 0.022-in SS mandibular brackets in

Roth prescription with 0^0 tip and 0^0 torque were used. Stainless steel brackets were used because of its routine application in orthodontics. Mandibular incisor brackets were selected because of its 0^0 tip and 0^0 torque as the incorporated tip and torque values will affect the testing value. Another reason for choosing these brackets was because the slots were flat and they could be mounted without inclination or angulation. The 0.022-inch slot have some definite advantages in space closure. It also offers a great range in wire selection. Rectangular stainless steel orthodontic wire sections .019" \times .025" were chosen as these wires are most commonly used for sliding in 0.022" bracket slot. These wires also do not undergo as much deflection as lighter wires, however, they show a lower friction coefficient when compared with the thicker ones^{57,21,118}.

The mode of engaging arch wire to the bracket also influences the magnitude of friction as it is directly proportional to the force acting perpendicular to the direction of sliding¹⁰⁰. So various methods have been introduced to reduce the force with which the wire is pushed against the bracket slot by the ligation techniques. SS ligatures were used as a conventional method of ligation. Disadvantages include difficult to apply, requires more chair side time, less hygienic, discomfort to the patient. Studies have found out that SS ligatures create less friction when compared with elastic ligatures^{28,24}. But there is great operator variability in tightness imparted by the stainless steel ligatures which in turn produce large range of friction values during its use^{49,32}.

Elastomeric ligatures are more commonly used for clinical purpose. The advantages include easy to apply, more comfortable to the patient, more hygienic compared to SS ligature, less chair time. The disadvantages are increased bacterial accumulation on the teeth and surfaces adjacent to brackets, the chances of incomplete seating of orthodontic wire, the possibility of bending the wire during orthodontic tooth sliding¹¹⁶. As an attempt to further reduce the friction, various new techniques have been introduced like self ligating brackets, modified elastomeric ligatures. One of this type is elastomeric modules coated with hydrophobic polymers using Metafasix technology (Super SlickTM) introduced in 2000 (TP Orthodontics, La Porte, USA).

Orthodontic treatment is predominantly carried out in adolescents. Oral hygiene is a matter of concern in most of these patients. In order to reduce the demineralization associated with poor oral hygiene and to enhance the cleanliness, orthodontists prescribe fluoride mouth rinse for their patients. Commercially available fluoride mouth rinses are based on acidulated phosphate solutions with a pH of 5.1. This acidic pH will increase the corrosion of the stainless steel wire and alter the surface characteristics.

In this study, commercially available 0.019x 0.025' straight stainless steel wires were cut into 8cm wire segments. 90 wire samples were prepared. Custom made templates made of acrylic were prepared with dimension of 4 "x 2" x 1". Horizontal and vertical reference lines were scribed on the template with commercially available permanent markers. Vertical lines were marked

almost at the center parallel to the long axis of the template. Horizontal lines were marked perpendicular to the vertical line just 1 cm off the lower end of the template. 90 templates of this type were prepared. At the point of intersection of these two lines, a bracket of the test sample was stabilized using industrial adhesive (Fevikwik) with the slot parallel to the vertical line to act as a guide for the reproducible bond position. 90 templates with brackets fixed on it were divided into three groups –Group A,B and C. In Group A clear elastomeric modules were used for ligation. In group B, stainless steel ligatures were used for wire engagement with the bracket using Mathieu forceps. In Group C, Super slick modules were used for ligation. All ligations were engaged to the wire segments with the ends projecting 25mm beyond the lower end of the acrylic template.

Testing was carried out in three environmental conditions – dry, wet and after fluoride application for each group. Tests were first conducted for each sample group under dry condition. In wet conditions, friction tests were conducted after samples were soaked in artificial saliva for a period of 10 minutes. Next Bracket-Wire assembly was immersed in fluoride solutions, for 1.5 hours. The selection of 90 minutes as immersion time in fluoride mouth rinse as it is approximating 3 months of 1-minute daily topical fluoride treatments and tests were conducted.

Friction for all three groups under three environmental conditions were tested at room temperature on an Autograph AG-IS Shimadzu Precision Universal Tester, Shimadzu, Japan, with a crosshead speed of 20 mm/ min over

an 8-mm stretch of archwire. On the machine, tensile mode was selected and a load was adjusted to 5 Newtons to pull the wire segments. The selection of 5 Newtons as pulling tensile force was to help record the force variation during the procedure in minute level. The testing machine had an upper and lower member. The upper member of the machine engaged one end of the vertically oriented archwire, which was inserted in the bracket slots, and it pulled the archwire upwards while the lower member of the machine held the mounting template in place. The force required to initiate the sliding was measured by the computer in Newton in a digital graphical read out. The peak of the graph was selected for static friction values.

Analysis of Friction Test:

The mean static frictional resistance of mandibular central incisor stainless steel brackets with 0.019x0.025' SS were compared and evaluated using three ligation methods under three environmental conditions. Comparison of frictional resistance was done under dry condition for three methods of ligation. The results demonstrated that conventional elastomeric modules (0.986993 ± 0.1071609) had the highest frictional forces under dry condition. This is in concordance with the study done by **Khambay**⁶³ (2004), **Kusy**⁷¹ (1999), **Iwasaki**⁴⁹ (2003), **Griffith, Sheriff, Ireland**¹⁰² (2005), but when the frictional resistance was compared between elastomeric modules and stainless steel ligatures (0.921447 ± 0.2245589), no significant difference was observed, even though the mean friction values were lower for stainless steel ligatures. This is in agreement with the study done by **Frank and Nikolai**²⁸

(1980), **Edwards**²⁴ (1995), but disagrees with studies of **Riley**⁹⁸ (1979), **Schumacher**¹⁰⁶ (2005). In their findings there was a significant increase in friction when stainless steel ligatures were used instead of elastomeric ligatures. There was a significant difference in friction when elastomeric ligatures and super slick ligatures (0.825470 ± 0.0657037) were compared ($P < 0.05$). Super slick ligatures demonstrated the lowest frictional resistance. This is in agreement with the study done by **Khambay**⁶³ (2004), **Hain. M**³⁸ (2003) but in disagreement with the study done by **Griffith, Sheriff, Ireland**¹⁰² (2005). Statistical analysis demonstrated a significant difference when super slick ligatures were compared with stainless steel ligatures. ($P < 0.05$).

Calculation of frictional resistance was done in three ligation methods under wet condition using artificial saliva. When the values obtained were compared among three groups, statistics demonstrated a significant difference between elastomeric – super slick groups ($P < 0.001$) and stainless steel -super slick groups ($P < 0.05$). But there was no significant difference in friction between elastomeric group and stainless steel group, even though the mean friction values were higher for elastomeric modules (1.063657 ± 0.1062004) than stainless steel ligatures (0.982780 ± 0.3044085). Of all the three groups, super slick ligation demonstrated lowest mean frictional values (0.841580 ± 0.0468680) similar to that of in the dry condition. This was in agreement with a technical paper on the performance of super slick by **Devanathan D**¹⁸ (2000).

The same sample groups were tested after fluoride mouth rinse application and values are compared statistically. Results obtained show values with a similar pattern to that under wet condition. The mean frictional resistance was highest for elastomeric modules (1.265783 ± 0.1569087). When stainless steel was used, the mean frictional resistance (1.205583 ± 0.2353873) was lower than that of elastomeric modules. But this not significant according to the statistical analysis. Friction was lowest when super slick was used as ligation. (0.897147 ± 0.1024465). Statistical analysis demonstrated a significant difference in frictional values between elastomeric modules-super slick groups ($P < 0.001$) and stainless steel – super slick groups ($P < 0.001$).

When friction was compared using elastomeric modules as ligation among three environmental conditions, mean frictional value under dry condition had the least friction than other two environmental conditions. Static friction under dry –elastomeric combination was (0.986993 ± 0.1071609), while under wet condition using artificial saliva it was (1.063657 ± 0.1062004). The increase in friction after the wet condition was not statistically significant compared to dry condition. This result disagrees with the study done by **Thurrow**¹²⁰ (1975) and **Baker**⁶¹ (1987). According to them frictional resistance decreased in the presence of artificial saliva. After fluoride application, friction was increased (1.265783 ± 0.1569087). This result correlates well with the studies of **Chia-Tze Kao**¹³ et al (2006). The difference in friction was highly significant when dry-after fluoride application and wet – after fluoride application were compared ($P < 0.001$). This might be due to the

increased corrosion of brackets in fluoride-containing solutions and an acidic environment. **Hwang CJ⁴⁶ (2001), Huang HH⁴⁴ (2003).**

When static frictional resistance was evaluated using stainless steel as ligation under three environmental conditions, mean frictional resistance was least under dry condition (0.921447 ± 0.2245589). Under wet conditions friction increased when compared to the dry condition (0.982780 ± 0.3044085). But this increase is not statistically significant. These findings were in concordance with the studies done by **Edward 1995²⁴, Stannard Etal, Hanne¹¹ et al, (1986), Thorteson And Kusy³⁴ (2003) Kusy And Whitley⁷⁰ (1997), Kusy and Whitley⁶⁸ (1990).** There is a significant increase when friction is compared after fluoride application (1.205583 ± 0.2353873) with dry condition ($P < 0.001$). When the friction is compared between wet and after fluoride application there was a statistically significant difference ($P < 0.001$). The increased standard deviation associated with stainless steel ligatures as ligation in friction showed that these ligatures produce variable ligation force **Iwasaki LR, Beatty MW, Randall CJ⁴⁹ 2003.**

Super Slick modules as ligation for brackets and wire were tested for friction under three environmental conditions in this study. The results showed the mean frictional resistance was least under dry condition (0.825470 ± 0.0657037). Under wet conditions friction increased when compared to the dry condition (0.841580 ± 0.0468680). But this increase was not statistically significant. The resistance was highest after fluoride application (0.897147 ± 0.1024465). Statistically significant difference was observed when

dry-fluoride application ($p < 0.001$) and wet –fluoride application ($p < 0.05$) was compared.

SUMMARY AND

CONCLUSION

Summary and Conclusion

The type of ligation and the materials used for ligation have a considerable influence on friction in Orthodontics. The magnitude of friction could also be influenced by various intra oral environmental condition which may alter the properties of ligature materials. This study was conducted to evaluate the influence of three methods of ligation on friction and the effect of fluoride mouth rinse on friction. From the results obtained it was concluded that

1. Three ligation methods namely elastomeric modules, stainless steel, super slick were tested for friction. Among these, elastomeric modules showed the highest resistance, and super slick demonstrated least resistance and Stainless steel ligatures has frictional resistance in between. The values obtained for SS is subjected to intra operator variability and hence could vary.
2. Under three environmental conditions namely dry, wet and after fluoride application, friction was highest after fluoride application. No significant difference in friction was found when the bracket archwire couple was lubricated with artificial saliva.

In order to enhance sliding during treatment mechanics, low friction ligatures like super slick can be used. Fluoride containing mouth rinses and prophylactic pastes can considerably increase the friction between stainless steel brackets and archwires as it might corrode the surface of these metal attachments.

LIMITATIONS

LIMITATIONS OF THE STUDY

1. The study was conducted in a stable in vitro condition. But intra oral environment shows fluctuations in temperature and pH levels due to the exposure of food and acidic beverages. This study didn't explore the effect of the oral environment on friction.
2. In this study, friction tests using wet condition were conducted after soaking in artificial saliva for 10 minutes . This did not take into account, the corrosive effect of artificial saliva in metallic brackets and force decay of elastomerics over a long period of time.

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